Studies
in
Arc Welding

DESIGN, MANUFACTURE and CONSTRUCTION

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THE JAMES F. LINCOLN ARC WELDING FOUNDATION
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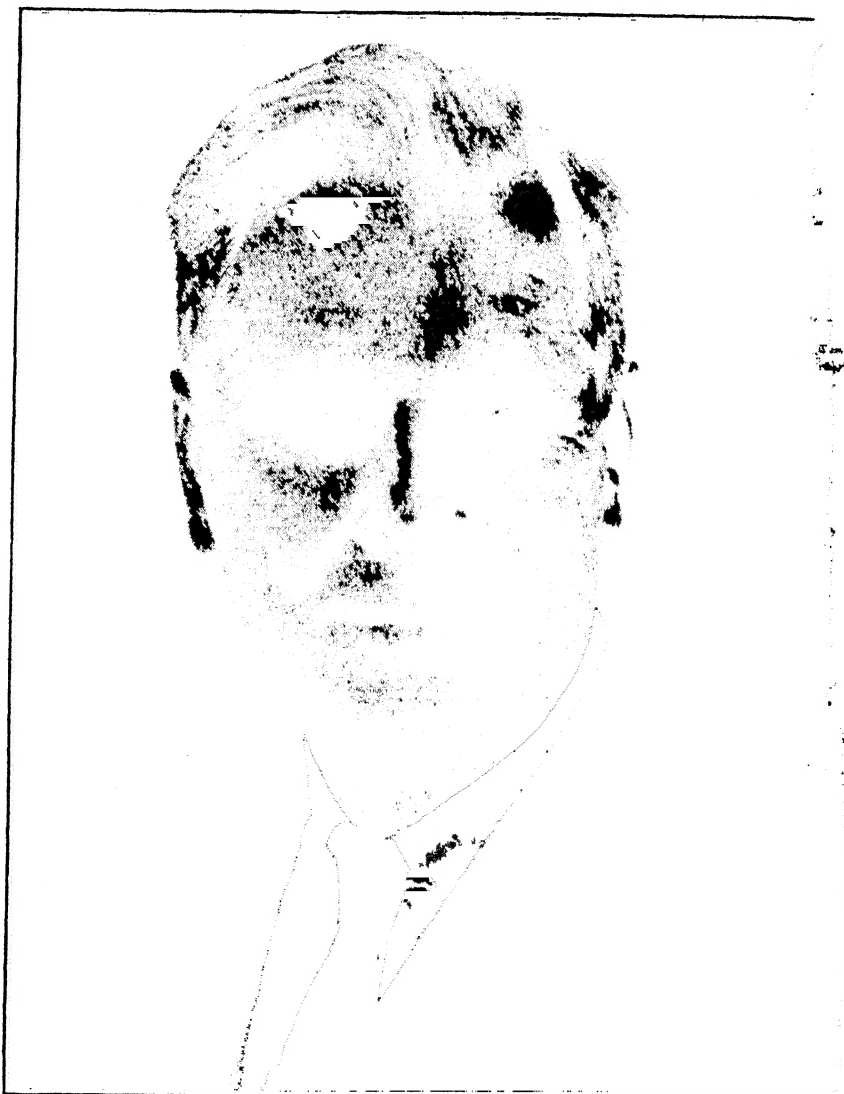
This book is dedicated to scientific progress of arc welding.

J. F. Lincoln, president of the Lincoln Electric Co , Cleveland, Ohio, anc pioneer in arc welding development, in whose honor the James F. Lincol Arc Welding Foundation was created.

Preface

TUDIES in Arc Welding" assumes a place of special importance in the rature of science, education and industry. The volume's contents reflect intensive application of the welding process during an era of world history which the United States took up the tremendous task of arming itself and allies for war. The book is the work, not of one person but of 113 making haustive studies in their own fields in which they have had long experience. e findings of these authors, who are executives, engineers, designers and ficials of production, construction and maintenance, while representing vital ntributions to war production, will provide the soundest possible basis for onomic stabilization during the post-war period.

The 98 award papers, which comprise "Studies in Arc Welding," were lected as outstanding in the 1940-42 Progress Program. In order to make e selection, the entire group of 408 papers which received awards in the rogram were considered in the light of originality, value of information and oroughness in treatment of subject matter. The omission of any paper is not be taken, in any sense of the word, as a reflection or criticism of the paper. This follows since in terms of interest and value all of the papers possess questioned merit. In the final selection, consideration had to be given to the number of papers which could be included to provide a volume of greatest value without becoming of a size impractical for easy reference.

Virtually all of the papers are reproduced in complete form, as regards both text and illustrations. A few papers which, in their original form, were too lengthy for complete reproduction, are included as comprehensive briefs without loss of pertinent text matter or illustrations. At the beginning of each paper is a brief summary of the subject matter prepared by the Jury of Award.

All papers contained herein were submitted to and approved by the United States Office of Censorship before publication. This was done to bide, in spirit and form, with the wishes of the federal government regarding uch matters.

"Studies in Arc Welding" should provide a most valuable aid in further-ing scientific and industrial progress and in extending the industrial, commer-cial, economic, and social benefits which are inherent in the welding process.

In publishing "Studies in Arc Welding," the James F. Lincoln Arc Weld-ing Foundation, knowing the tremendous value to industry of the information ontained in this book, herewith expresses its appreciation to all those who articipated in the Progress Program. Without the earnestness, thoroughness nd exactness with which the participants carried out their studies, this vol-ume would not have been possible.

A. F. DAVIS and ED C. POWERS, *Editors.*

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Section IX — Machinery (Continued)

Alphabetical List of Authors

ALLARDT, E. W., Mechanical Engineer, Babcock and Wilcox Tube Co., Beaver Falls, Pa. Award: $700. Title of paper: "Assembly of Five Separate Machines." See Section IX, page 756.

AMIRIKIAN, A., Designing Engineer, Bureau of Yards and Docks, Navy Department, Washington, D. C., co-author with Captain C. A. Trexel. Joint award: $13.700. Title of paper: "Welded Caissons for Naval Dry Docks." See Section V, page 454.

ANDREWS, F. H., Welding Superintendent, Paterson Boiler & Tank, Inc., Paterson, N. J., co-author with Louis LaGreca. Joint award: $500. Title of paper: "Gasoline Engine for Racing Automobile." See Section I, page 22.

ARMOUR, W. W., Vice-President, Armour's Pattern Shop Co., Welding Engineers, Worcester, Mass. Award: $150. Title of paper: "Welded Water Wheel Center Casing." See Section VIII, page 718.

ARONSON, MARK, Research Engineer, United States Navy Yard, Philadelphia, Pa., co-author with Edward A. Foehl. Joint award: $250. Title of paper: "Tilting Table for Armour Plate Production." See Section IX, page 933.

ATKIN, WILLIAM, Naval Architect, Atkin Naval Architecture, Darien, Conn. Award: $1,500. Title of paper: "Small Boats Arc Welded." See Section IV, page 324.

ATKINSON, E. H., Mechanical Engineer, Fulton Metal Bed Manufacturing Co., Atlanta, Ga. Award: $250. Title of paper: "Bed Rails and Bed Springs." See Section VI, page 526.

AVERITT, CARL RAY, Assistant Blacksmith Foreman, Paducah, Ky. Award: $500. Title of paper: "Fabrication of Steam Locomotive Cylinder." See Section III, page 282.

BARRON, WALTER E., Foreman in charge of welding, Heisler Locomotive Works, Erie, Pa. Award: $250. Title of paper: "Arc Welded Construction of 'Fireless' Locomotive." See Section III, page 201.

BAXTER, JOE, JR., Sales Engineer, Shartle Brothers Machine Co., Middletown, Ohio. Award: $250. Title of paper: "Arc Welding Applied to Waxing Machine." See Section IX, page 1015.

BECKER, ERNEST R., Assistant Chief Engineer, The Liquid Carbonic Corp., Chicago, Ill. Award: $700. Title of paper: "Bottle-Washer Redesigned for Welding." See Section IX, page 1196.

BENEDEK, DR. ELEK K., Consulting Engineer, General Hydraulic Co., Cleveland, Ohio. Award: $500. Title of paper: "Aircraft Propeller Blade." See Section II, page 121.

BERKELEY, JOHN PEYTON, Chief Engineer, Berkeley Equipment Co., Corry, Pa. Award: $500. Title of paper: "Arc Welded Motor Drives for Machine Tools." See Section IX, page 960.

BIEDERMAN, EDWARD G., Welding Engineer, Fisher Tank Division, General Motors Corp., Flint, Mich. Award: $150 Title of paper: "Welding of Armor Plate for Tank Production." See Section I, page 36.

BIER, P. J., Senior Engineer, Bureau of Reclamation, Denver, Colo. Award: $2,700. Title of paper: "Arc Welded Power Penstocks." See Section VIII, page 697.

BIRKMEYER, PAUL J., Engineer, Western Union Telegraph Co., New York, N. Y. Award: $2,700. Title of paper: "Welded Housings for Telegraphic Printers." See Section VI, page 531.

BLACK, JAMES, Vice-President in Charge of Engineering, Trailer Company of America, Oakley, Cincinnati, Ohio. Award: $500. Title of paper: "15-Ton Low-Bed Trailer Frame." See Section I, page 93.

BLAZEY, LAWRENCE C., Secretary, Designers for Industry, Cleveland, Ohio, co-author with George B. Rogers. Joint award: $150. Title of paper: "Arc Welding and Modern Steel Houses." See Section V, page 449.

BOWLES, J. C., Superintendent of Equipment, the Community Traction Co., Toledo, Ohio. Award: $250. Title of paper: "Construction of Rail Grinding Car." See Section III, page 277.

BROOKING, WALTER J., Director of Testing and Research, R. G. LeTourneau, Inc., Peoria, Ill. Award: $1,500. Title of paper: "Tractor Transmission Case and Frame Assembly." See Section IX, page 1022.

BRUMMERSTEDT, EGON F., Mechanical Engineer, Petroleum Division, Foster Wheeler Corp., New York, N. Y. Award: $700. Title of paper: "High-Temperature Vacuum Fractionating Tower." See Section IX, page 1089.

BUERER, WAYNE, Assistant Professor, Mechanical Engineering, Mechanical Engineering Laboratory, Oklahoma Agricultural and Mechanical College, Stillwater, Okla. Award: $700. Title of paper: "Experimental 7½-Ton Refrigeration Plant." See Section IX, page 852.

BULGER, MARTIN, Foreman, American Airlines, LaGuardia Field, Jackson Heights, N. Y. Award: $250. Title of paper: "Redesign of Airplane Engine Tail Pipe." See Section II, page 130.

CANDLIN, J. E., JR., Assistant Engineer, Pullman-Standard Car Manufacturing Co., Chicago, Ill., co-author with A. M. Unger. Joint award: $3,700. Title of paper: "Underframes for All Welded Railroad Passenger Cars." See Section III, page 252.

CARTER, ROBERT M., Engineer, Line Maintenance Department, Stanolind Pipe Line Co., Tulsa, Okla. Award: $500. Title of paper: "Batching Scraper for Crude Oil Pipe Lines." See Section IX, page 1104.

CLARKE, FRED, Instructor of Welding, Moose Jaw Technical High School, Moose Jaw, Sask., Canada. Award: $150. Title of paper: "Arc Welded Sculpture." See Section V, page 490.

COCHRAN, VIRGIL, Assistant Superintendent, LeTourneau Co. of Georgia, Toccoa, Ga Award: $3,700. Title of paper: "Operating a Plant Weldery." See Section VII, page 652.

CONABEE, R. S., Engineer, Lukenweld, Inc., Coatesville, Pa. Award: $1,700. Title of paper: "Welded Steel in Paper-Making Machinery." See Section IX, page 979.

DAVIS, ERNEST, Chief Engineer, The Prosperity Company, Inc., Syracuse, N. Y. Award: $500. Title of paper: "Improved Synthetic Cleaning Machines." See Section IX, page 1277.

DEARIE, JOHN A., Draftsman, Western Union Telegraph Co., New York, N. Y. Award: $500. Title of paper: "Arc Welded Bicycle Racks." See Section IX, page 1183.

DILLON, JOHN F., JR., Welding Engineer, LeTourneau Company of Georgia, Toccoa, Ga. Award: $700. Title of paper: "Low-Cost Grading and Hauling." See Section I, page 3.

DONALDSON, W. G., Foreman of Electrical Department, Standard Oil Co. of Indiana, Sugar Creek, Mo. Award: $250. Title of paper: "Speedy Welding Cable Connector." See Section IX, page 777.

DRENKARD, ADAM, JR., Engineer, Western Union Telegraph Co., New York, N. Y. Award: $700. Title of paper: "Parts for a Receiving–Switching–Transmitting Unit." See Section IX, page 880.

DREWES, FRED H., Welding Engineer, W. P. Thurston Co., Engineers and Contractors, Richmond, Va. Award: $3,700. Title of paper: "Developing and Conducting a Commercial Welding or Job Shop." See Section VII, page 547.

ECKLEY, WILLIAM A., Designer, Pioneer Engineering Works, Inc., Minneapolis, Minn., co-author with Ralph W. Heer. Joint award: $500. Title of paper: "Welding Jaw Crusher Bases." See Section IX, page 1003.

ELDRIDGE, E. J., Draftsman, Welded Products, Pty. Ltd., Sydney, Australia, co-author with John O. Ogden. Award: $700. Title of paper: "Fabricated Rolled Steel Machinery." See Section IX, page 725.

ENKE, GLENN L., Assistant Chief Engineer, Utah Pomeroy Morrison, Provo, Utah. Award: $2,700. Title of paper: "Steel and Concrete Bridges Compared." See Section V, page 362.

EVANS, W. S., Materials and Process Engineer, Curtiss-Wright Corporation, Airplane Division, Lambert Field, St. Louis, Mo. Award: $1,250. Title of paper: "Arc Welding of Airplane Parts." See Section II, page 159.

FEY, REGIS F., Structural Engineer, Pittsburgh-Des Moines Steel Co., Pittsburgh, Pa. Award: $2,700. Title of paper: "Modern Welded Blast Furnace." See Section IX, page 1112.

PFIELD, PAUL, Materials Engineer, Bethlehem Steel Co., Quincy, Mass., co-author with Carlton G. Lutts. Joint award: $500. Title of paper: "Welding of Finished-Machined Casting." See Section IX, page 805.

FISHER, C. DONALD, Designer and Draftsman, Sprout, Waldron and Co., Muncy, Pa. Award: $500. Title of paper: "Special Duty Steel Plate Fan." See Section IX, page 870.

FITCH, JAMES W., Automotive Engineer, Kenworth Motor Truck Corp., Seattle, Wash. Award: $1,500. Title of paper: "Streamlined Fire Truck." See Section I, page 54.

FITCH, T. S., President, Composite Steels, Inc., Washington, Pa., co-author with L. W. Townsend. Joint award: $500. Title of paper: "Carbon Arc Welding in Production of Clad Steels." See Section IX, page 1131.

FOEHL, EDWARD A., Naval Architect, United States Navy Yard, Philadelphia, Pa. Co-author with Mark Aronson; see above.

GERSTACKER, WILLIAM G., Development Engineer, Union Metal Manufacturing Co., Canton, Ohio. Award: $500. Title of paper: "Welded Design of Tapered Tube Booms for Cargo Ships." See Section IX, page 847.

GRAVES, GEORGE J., President, Graves & Son Boiler & Mfg. Co., Inc., Jamestown, N. Y. Award: $250. Title of paper: "De Luxe House Trailer." See Section I, page 102.

GRUVER, JOHN H., Designer, Addressograph-Multigraph Corporation, Euclid, Ohio, Award: $500. Title of paper: "Special Check Writing Machine." See Section IX, page 896.

HARRIS, LEMUEL J., Manufacturing Foreman, Holland Furnace Co., Holland, Mich. Award: $250. Title of paper: "Redesign of Oil-Gas Furnace." See Section IX, page 1189.

HAUPT, WALTER H., Mechanical Engineer, Kelley Koett Manufacturing Co., Covington, Ky. Award: $700. Title of paper: "Base of Tilting Fluoroscope." See Section IX, page 951.

HAWKINS, GEORGE W., Consulting Engineer, Anderson Nichols Associates, Boston and New York. Award: $2,500. Title of paper: "Quantity Production of Cargo Carriers." See Section IV, page 305.

HEER, RALPH W., Assistant Chief Engineer, Pioneer Engineering Works, Inc., Minneapolis, Minn. Co-author with William A. Eckley; see above.

HOLMES, RICHARD H., Production Design Engineer, Curtis Aircraft Co., Buffalo, N. Y. Award: $700. Title of paper: "Arc Welded Tubular Aircraft Jigs." See Section IX, page 919.

HRUSKA, JOHN H., Chief Inspector, Electro-Motive Division, General Motors, LaGrange, Ill. Award: $1,700. Title of paper: "Arc Welded Diesel Electric Freight Locomotive." See Section III, page 181.

JACKSON, J. O., Chief Engineer, Pittsburgh-Des Moines Steel Co., Pittsburgh, Pa. Award: $3,700. Title of paper: "Liquefied Gas Storage Containers." See Section VIII, page 667.

JACOBSON, E. W., Design Engineer, Gulf Research and Development Company, Pittsburgh, Pa., co-author with F. F. Vewsaw. Joint award: $250. Title of paper: "Wheel Mounting for Racing Automobile." See Section I, page 62.

KNERR, H. S., Lt. Junior Grade, U. S. Navy, Navy Yard, Portsmouth, N. H. Award: $500. Title of paper: "Welded Steel Boat Design." See Section IV, page 333.

LAGRECA, LOUIS, Owner, LaGreca Machine Co., Paterson, N. J. Co-author with F. H. Andrews; see above.

LEBERT, H. A., Inspector, United Airlines Transport Corporation, Cheyenne, Wyo., co-author with S. B. Willoughby. Joint award: $2,500. Title of paper: "Arc Welding Airplane Boilers." See Section II, page 148.

LOVE, J. R., Manager and Engineer, Love Tractor, Inc., Eau Claire, Mich. Award: $500. Title of paper: "One-Piece Design of Farm Sprayer." See Section IX, page 1163.

LUTTS, CARLTON G., Materials Engineer, Navy Yard, Boston, Mass. Co-author with Paul Ffield; see above.

MARQUARDSEN, R. P. V., Structural Designer, The Sanitary District of Chicago, Chicago, Ill. Award: $250. Title of paper: "Efficiently Rigid Arc Welded Connections." See Section V, page 350.

MARTIN, P. W., Secretary and Chief Engineer, Smalley General Co., Bay City, Mich. Award: $250. Title of paper: "Bed for Milling Propeller Blades." See Section IX, page 746.

MCCLELLAN, CLARENCE, Director of Welding, McClellan & Sons Super Service Station, Menomonie, Wis. Award: $2,700. Title of paper: "Organization of Garage or Service Station for Arc Welding." See Section VII, page 601.

MCGEE, WILLIAM A., Mechanical Engineer, The New York Central Railroad Co., Cleveland, Ohio. Award: $100. Title of paper: "All Arc Welded Steam Line." See Section VIII, page 721.

MCKAY, S. R., McKay Engineering Company, Cleveland, Ohio. Award: $250. Title of paper: "Steel Framing for Residences." See Section V, page 435.

MIDNIGHT, STANLEY A., Assistant Chief Draftsman, American Ship Building Co., Cleveland, Ohio. Award: $3,700. Title of paper: "Hidden Advantages of Arc Welded Ship Construction." See Section IV, page 289.

MILLER, DR. JOHN L., Chief Metallurgist, Gun-Mount Division, The Firestone Tire and Rubber Co., Akron, Ohio. Award: $11,200. Title of paper: "Redesigned 40 MM. Anti-Aircraft Gun Carriage." See Section IX, page 1248

MONSON, HUGH T., Plant Engineer, The Euclid Road Machinery Co., Euclid, Ohio. Award: $700. Title of paper: "Downdraft Ventilation for Welding Shop." See Section IX, page 900.

MORK, GEORGE W., Engineer, Bucyrus-Erie Company, South Milwaukee, Wis., co-author with Howard Squires. Joint award: $500. Title of paper: "Redesign of Main Frames for Tractor Bullgrader." See Section IX, page 1080.

MOYER, ROBERT E., JR., Vice-President in charge of Engineering, Heilman Boiler Works, Allentown, Pa. Award: $100. Title of paper: "The Drumless Boiler." See Section VIII, page 693.

MULLER, JOHN F., Sales Engineer, The American Pulley Company, Philadelphia, Pa., co-author with Gonzalo C. Munoz. Joint award: $1,300. Title of paper: "Arc Welded Suspension for Air Conditioning System." See Section III, page 262.

MUNOZ, GONZALO C., Secretary-Treasurer, The American Pulley Company, Philadelphia, Pa. Co-author with John F. Muller; see above.

NIEDERHOFF, A. E., Senior Engineer of Design, U. S. Army Engineers, Portland, Ore. Award: $500. Title of paper: "Thoughtful Welding of Machine Parts." See Section IX, page 913.

NORTHROP, JOHN K., President, Northrop Aircraft, Inc., Hawthorne, Calif., co-author with Vladimir H. Pavlecka. Joint award: $3,700. Title of paper: "Arc Welding of Magnesium Aircraft Structures." See Section II, page 132.

OGDEN, JOHN O., General Manager and Director, Welded Products, Pty. Ltd., Sydney, Australia. Co-author with E. J. Eldridge; see above.

PAVLECKA, VLADIMIR H., Chief of Research, Northrop Aircraft, Inc., Hawthorne, Calif. Co-author with John K. Northrop; see above.

PETERSON, H. B., American Can Company, San Francisco, Calif. Award: $500. Title of paper: "Arc Welding in Automatic Can-Testing Machine." See Section IX, page 1203.

PRIEST, H. MALCOLM, Engineer, U. S. Steel Corp., Subsidiaries, Pittsburgh, Pa. Award: $2,700. Title of paper: "Welded Design of 250-Ton Flat Car." See Section III, page 228.

REISS, ERNEST, General Manager and Partner, The Art Chrome Company of America, Boston, Mass. Award: $3,700. Title of paper: "Arc Welding of Plated Tubular Furniture." See Section VI, page 507.

RENN, ALAN C., Assistant Foreman in Charge of Arc Welding, Vultee Aircraft, Inc., Vultee Field Division, Vultee Field, Calif. Award: $100. Title of paper: "Arc Welded Tubular Fuselage." See Section II, page 178.

RIORDAN, JOHN M., Chief Engineer, Bonnar-Vawter Fanform Co., Cleveland, Ohio. Award: $500. Title of paper: "Collating Machine of Improved Design." See Section IX, page 1244.

ROGER, JOHN P., Plant Engineer, The Babcock and Wilcox Co., Barberton, Ohio. Award: $150. Title of paper: "Welding a Locomotive Boiler." See Section III, page 214.

ROGERS, GEORGE B., General Contractor, Lakewood, Ohio. Co-author with Lawrence C. Blazey; see above.

ROSSMANN, PETER F., Chief of Miscellaneous Developments Research, Research Laboratory, Curtiss-Wright Corporation, Airplane Division, Buffalo, N. Y. Joint award: $1,500. Title of paper: "Welding Aircraft Engine Mounts Economically." See Section II, page 111.

RUTTEN, WALTER, Partner and Factory Superintendent, Railoc Company, Plainfield, Ill. Award: $250. Title of paper: "Production Machine for Domed Silo Roofs." See Section IX, page 764.

SALK, CLIFFORD A., Carman, Great Northern Railway, St. Cloud Shops, St. Cloud, Minn., co-author with Ray F. Theisen. Joint award: $250. Title of paper: "Arc Welded Conversion of Tenders Into Tank Cars." See Section III, page 247.

SAXE, VAN RENSSELAER P., Consulting Engineer, Baltimore, Md. Award: $700. Title of paper: "Welded Airplane Hangar." See Section V, page 343.

SCHEYER, EMANUEL, Assistant Designing Engineer, Designs Division, Board of Transportation, New York, N. Y. Award: $1,500. Title of paper: "Welded Steel Bents for Subways." See Section V, page 470.

SHEFELTON, W. E., Production Manager, R. D. Cole Manufacturing Co., Newnan, Ga. Award: $500. Title of paper: "Welded Lining of Horizontal Processing Tanks." See Section IX, page 1225.

SHIMKIN, B. M., Master Science Civil Engineer and Civil Engineer and Associate Bridge Designer Engineer, Bridge Department of State of California, Sacramento, Calif. Award: $250. Title of paper: "Trusses for Swing Bridge." See Section V, page 414.

SIMPSON, HOWARD W., Chief Engineer, Detroit Harvester Co., Detroit, Mich. Award: $700. Title of paper: "Arc Welding in the Manufacture of Mowers." See Section IX, page 1145.

SLAGHT, W. W., Chief Engineer, Cleveland Steel Products Corp., Cleveland. Ohio. Award: $250. Title of paper: "Universal Joint Drive Shafts." See Section I, page 24.

SLYGH, EDWARD J., Campbell-Lowrie-Lautermilch Corp., Chicago, Ill. Award: $700. Title of paper: "T-Beams for Residences." See Section V, page 426.

SMITH, S. ARNOLD, Chief Engineer, The Whitlock Manufacturing Co., Hartford, Conn. Award: $1,300. Title of paper: "Design and Production of Heat Exchangers." See Section VIII, page 678.

SPENCER, ELDRIDGE T., Architect, San Francisco, Calif. Award: $1,500. Title of paper: "Pipe-Frame Office Chair." See Section VI, page 538.

SQUIRES, HOWARD, Manufacturing Engineer, Bucyrus-Erie Company, South Milwaukee, Wis. Co-author with George W. Mork; see above.

STANLEY, RICHARD W., Design Engineer, American Viscose Corp., Marcus Hook, Pa. Award: $700. Title of paper: "Redesign of Rayon Processing Machine." See Section IX, page 1211.

STONE, HERBERT, Assistant Works Manager, Markham and Co., Ltd., Chesterfield, England. Award: $1,500. Title of paper: "Large Water Turbine Installations." See Section IX, page 783.

STORATZ, G. J., Assistant Chief Engineer, The Heil Co., Milwaukee, Wis. Award: $3,700. Title of paper: "High-Speed Dirt Movers." See Section I, page 70.

STREITHOFF, C. PERRY, Structural Division Engineer, Engineering Works Division, Dravo Corporation, Pittsburgh, Pa., Award: $1,700. Title of paper: "Welded Revolving Cranes." See Section IX, page 815.

THEISEN, RAY F., Welder, Great Northern Railway, St. Cloud Shops, St. Cloud, Minn. Co-author with Clifford A. Salk; see above.

TOWNSEND, L. W., Vice-President, Composite Steels, Inc., Washington, Pa. Co-author with T. S. Fitch; see above.

TREXEL, CAPTAIN C. A., Director of Planning and Design, Bureau of Yards and Docks, Navy Department, Washington, D. C. Co-author with A. Amirikian; see above.

UNGER, A. M., Plant Engineer, Pullman-Standard Car Manufacturing Co., Chicago, Ill. Co-author with J. E. Candlin; see above.

VERSAW, F. F., Shop Superintendent, Gulf Research and Development Company, Pittsburgh, Pa. Co-author with E. W Jacobson; see above.

WAGNER, D. F., Chief Engineer, Wentworth & Irwin, Inc., Portland, Ore. Award: $1,500. Title of paper: "Arc Welding in Bus Construction." See Section I, page 27.

WEAVER, ELVERTON W., Consulting Design Engineer, Towmotor Co., Cleveland, Ohio. Award: $2,700. Title of paper: "Small-Truck for Loading Freight Cars." See Section I, page 45.

WEIDNER, VICTOR PAUL, Engineer, Western Union Telegraph Company, New York, N. Y. Award: $250. Title of paper: "Welded Display Holder for Printed Matter." See Section VI, page 543.

WHITTAKER, LLOYD A., Chief Engineer, Thomson National Press Co., Franklin, Mass. Award: $700. Title of paper: "Arc Welding in Press Machinery." See Section IX, page 1232.

WILLIS, JOHN F., Engineer of Bridge Design, Connecticut State Highway Department, Hartford, Conn. Award: $1,300. Title of paper: "Welded Grade Separation Structure." See Section V, page 376.

WILLOUGHBY, S. B., Arc Welder, United Airlines Transport Corporation, Cheyenne, Wyo. Co-author with H. A. Lebert; see above.

WOODARD, JOSEPH H., Co-owner and Plant Manager, Lee L. Woodard Sons, Owosso, Mich. Award: $1,300. Title of paper: "Wrought Iron Furniture Manufacturing." See Section VI, page 518.

WOLFE, GEORGE F., Chief Plant Engineer, Engineering Works Division, Dravo Corporation, Neville Island, Pittsburgh, Pa. Award $2500. Title of paper: "Straight Line Mass Production Methods Speed the Defense Program." See Section VII, page 627.

The James F. Lincoln Arc Welding Foundation

THE James F. Lincoln Arc Welding Foundation has been widely acknowledged as an important aid to industry through its contributions to industrial, economic and social progress.

Through its Award Programs, the Foundation has stimulated and is stimulating widespread interest in the possibilities of the electric arc welding process as applied to industrial manufacture, fabrication, construction and maintenance work.

Valuable information contained in the award papers has been widely disseminated to stimulate and intensify the use of the electric arc process. Dissemination of this important information is accomplished through publication of abstracts of papers in literally hundreds of magazines; publication of the most outstanding papers in complete form in magazines; and publication of the books, "Arc Welding in Design, Manufacture and Construction," containing 109 of the outstanding papers from the 1937-38 Award Program and the present volume "Studies in Arc Welding," containing 98 of the most significant award studies in the 1940-42 program.

The Foundation's first award program was inaugurated early in 1937 and terminated with payment of $200,000 in September, 1938. A total of 382 awards were made ranging from $101.75 to $13,941.33.

The second study program, the $200,000 Industrial Progress Award Program, was sponsored during the period from January 1940 to June 1942. It terminated in October 1942 with the payment of $200,000 in 408 awards which range from $50 to $13,700.

By its study programs, the Foundation has called widespread attention to the many inherent advantages of arc welding and has stimulated the use of this process with pronounced benefits. For example, in the 1940-42 program it was shown that a possible annual saving of $1,825,000,000, including 7,000,000 tons of steel and 153,000,000 man hours of labor, was available by utilization of this modern process.

The Foundation more recently sponsored a $6,750 Engineering Undergraduate Award and Scholarship Program to stimulate study of the arc welding process by engineering students. This program was announced December 1st, 1942 and closed April 1st, 1943.

Why the Foundation Was Created

Regarding the creation of The James F. Lincoln Arc Welding Foundation in 1936, Mr. J. C. Lincoln, chairman of the board of directors of The Lincoln Electric Co., the founder, made the following statement which is quoted from the original deed of trust.

"Since the dawn of recorded time, man has struggled constantly to improve his conditions. Coping with many obstacles, he has developed great skill and ingenuity. Applied through the years, these talents have rewarded man with luxuries of which his ancestors never dreamed—the telephone, the radio, the automobile, the airplane, the railroad, the steamship, the skyscraper, the gigantic bridge—these modern wonders and many others are the products of man's skill and ingenuity.

"Recent years have seen the origin and development of an ingenious process which has great economic, social and commercial significance to mankind. That process is arc welding.

"It is, therefore, our belief that by encouraging and stimulating scientific interest in and study of arc welding, still greater benefits will result from man's skill and ingenuity. To this end, The Lincoln Electric Co. announces that it has created, in honor of its president, 'The James F. Lincoln Arc Welding Foundation'."

The Lincoln Electric Company
J. C. LINCOLN,
Chairman of the Board of Directors

Object and Purpose of the Foundation

"The object and purpose of The James F. Lincoln Arc Welding Foundation is to encourage and stimulate scientific interest in, and scientific study, research and education in respect of, the development of the arc welding industry through advance in the knowledge of design and practical application of the arc welding process, and to provide for the payment of awards, by prizes, to those persons who by reason of the excellence of their papers upon said subject may be selected in the manner herein provided as most worthy to receive such awards."

Trustees and Officers

The $200,000 Industrial Progress Award Program

The 1940-42 Progress Program was the second activity of The James F. Lincoln Arc Welding Foundation to encourage scientific progress of arc welding. It offered 458 awards.

The following information regarding awards is quoted from the Rules and Conditions governing participation in the Program:

"The 458 awards are grouped as follows:

"184 Divisional Awards:—1st, 2nd, 3rd and 4th awards of $700, $500, $250 and $150 respectively, in each of 46 Divisions.

"48 Classificational Awards:—1st, 2nd, 3rd and 4th awards of $3,000, $2,000, $1,000 and $800 respectively, in each of 12 Classifications.

"3 Main Program Awards:—1st, 2nd and 3rd awards of $10,000, $7,500 and $5,000 respectively.

"223 Additional Awards for Honorable Mention:—Awards of $100 each for 223 papers which do not share in any other award but which, in the opinion of the Jury of Award, deserve Honorable Mention. These 223 awards may be made for papers in any of the Divisions.

"The 184 Divisional Awards will be determined first. Then, from the papers receiving the 1st, 2nd, 3rd and 4th Divisional Awards in each Division of a particular Classification, papers will be selected to receive the 1st, 2nd, 3rd and 4th Classification Awards of the particular Classification, repeating the process for each Classification. From the Classificational award papers, papers will be selected to receive the 1st, 2nd and 3rd Main Program Awards. After the Divisional, Classificational and Main Program Awards have been determined, papers will be selected to receive the Honorable Mention Awards.

"For the paper selected as the best of all papers submitted, a 1st Grand Award of $13,700 will be made, composed of $700 as 1st Divisional Award, $3,000 as a 1st Classificational Award and $10,000 as 1st Main Program Award.

Subject Matter of Papers in the $200,000 Industrial Progress Award Program

The following definitions of subject matter for papers in the Progress Program are quoted from the Rules and Conditions of the Foundation governing participation:

"Papers are to be on the subject, *progress made by application of arc welding between January 1st, 1940, and June 1st, 1942.* The paper shall cover progress on but one of the following points:

"(a) Redesign and manufacture or construction of an existing machine, structure, building, manufactured or fabricated product of ferrous or non-ferrous metals, within the limits of the rules hereinafter prescribed, which was previously made in some other way and redesigned so that arc welding may be applied, in whole or in part, to its manufacture, fabrication or construction.

"(b) New design and manufacture or construction of a machine, structure, building, manufactured or fabricated product of ferrous or nonferrous metals, within the limits of the rules hereinafter prescribed, which was not previously made but which has been designed in whole or in part for the use of arc welding, the description to show how a useful result, which was impractical with other methods of construction, or could be better done by arc welding, is accomplished.

"(c) Organizing, developing and conducting a welding service. The welding service to be described in the papers may be conducted by Commercial Welders or Job Shops (G-1), Garages or Service Stations (G-2), Commercial Welderies (I-1), or Plant Welderies (I-2).

"(d) Developing, planning and performing maintenance or repair work with arc welding. The maintenance or repair work to be described in the papers may be Plant and Construction machinery and mechanical equipment of all kinds; also mobile equipment such as fleets of trucks, buses and taxicabs (L-1); or Structures and other structural applications of arc welding in maintenance (L-2), such as pipe lines, railroad tracks, bridge strengthening, and other such work, not covered under L-1.

"Note that the machine, structure, building, manufactured or fabricated product under (a) or (b) may be designed either in whole or in part for the use of arc welding.

"To qualify as to subject matter, the welding service as in (c) and the maintenance work as in (d), within the period January 1, 1940, to June 1, 1942, must have been either:

(1), planned and put into practice within the period;
or (2), put into practice within the period as result of plans made prior to the period.

Papers of otherwise equal merit will be preferentially rated in the above order.

Requirements As to Submission of Papers

"1. Paper shall be submitted in two copies, one signed, the other unsigned.

"2. Each copy shall be enclosed in a separate sealed envelope.

"3. THE SIGNED COPY:—The signed copy shall have the following information written on the cover or title page and on the outside of the envelope in which it is enclosed:

Name, address and signature of the author, or authors.
Name and address of company with which author is connected.
Relationship between the author, or authors, and the company or concern
Classification of the paper, as for example A-1, C-4, J-6, K-7, L-2, etc., depending upon the nature of the subject matter.

Name of individual or individuals to whom award check is to be made payable, and address of individual to whom it is to be mailed, if award is made for the paper.

A statement that data on the three Factors of Judgment are given in the paper.
A statement that cost data are given.
A statement that the work treated in the paper was carried on within the period—January 1st, 1940 to June 1st, 1942.
If paper may not be published, a statement to that effect.
If product, structure, or work used as subject is patented, a statement to that effect giving the full name and address of the person, or persons, from whom information regarding the patent is to be obtained.

"4. THE UNSIGNED COPY:—The unsigned copy shall have the following information written on the cover sheet and on the outside of the envelope in which it is enclosed:
Classification of the paper, as A-1, C-4, J-6, etc.
NOTE: On this unsigned copy of the paper and envelope no name or data other than classification are to be given.

"5. The two separate sealed envelopes, one containing the signed and the other the unsigned copy of the paper, are to be placed together in a large envelope, postage prepaid, and addressed: 'Secretary, The James F. Lincoln Arc Welding Foundation, P. O. Box 5728, Cleveland, Ohio,' and mailed, postmarked not later than midnight June 1st, 1942, and received in Cleveland not later than midnight July 1st, 1942.
Upon receipt thereof in Cleveland, the sender will be notified by mail.

"*Confidential Handling of Papers*—When received by the Secretary, the envelope in which both copies of the paper are enclosed will be opened and immediately the same identifying number will be given to the envelope containing the signed paper and the envelope containing the unsigned paper. The envelope containing the signed paper will be retained by the Secretary unopened and confidential. The envelope containing the unsigned paper, with the number identifying the author, and the classification and division for which the paper is entered, will be delivered, unopened, to the Jury of Award, with other contesting papers, at the close of the Program.

"The object will be to keep each paper confidential, without disclosure, until the Jury of Award considers the identified but unsigned paper. When the award papers are selected by the Jury of Award, proper certificate thereof will be made to the Foundation and then each award paper will be identified with its original paper on file with the Secretary."

Only papers contained in envelopes postmarked not later than June 1, 1942, and received in Cleveland not later than July 1, 1942, were accepted.

By letter of July 28, 1942, the Jury of Award of The James F. Lincoln Arc Welding Foundation certified to the Secretary its decisions concerning papers submitted in the Progress Program. The certification of papers, (See page xxv), was by number in accordance with the Rules of Award.

Upon receipt of the Jury's report, the Secretary and Assistant Secretary of the Foundation, identified the authors of the award-winning papers by reference to the various records.

Industrial Classifications and Subject Divisions of the $200,000 Progress Program

The Progress Program was divided into 12 industrial classifications covering 46 subject divisions as given below:

Industrial Classification	Subject Divisions
A AUTOMOTIVE	A-1 Engines A-2 Bodies A-3 Frames A-4 Trailers
B AIRCRAFT	B-1 Engines B-2 Fuselages
C RAILROAD	C-1 Locomotives C-2 Freight Cars C-3 Passenger Cars C-4 Locomotive and Car Parts
D WATERCRAFT	D-1 Commercial and Naval D-2 Pleasure
E STRUCTURAL	E-1 Buildings and Similar Structures E-2 Bridges E-3 Houses E-4 Miscellaneous
F FURNITURE and FIXTURES	F-1 House F-2 Office
COMMERCIAL WELDING	G-1 Commercial Welders or Job Shops G-2 Garages or Service
H CONTAINERS	H-1 Contents Stationary (tanks, etc.) H-2 Contents Moving (pipe lines, etc.)
WELDERIES	I-1 Commercial Welderies I-2 Plant Welderies

Industrial Classification	Subject Divisions
J FUNCTIONAL MACHINERY	J- 1 Metal Cutting J- 2 Metal Forming J- 3 Electrical J- 4 Prime Movers J- 5 Conveying J- 6 Pumps and Compressors J- 7 Business J- 8 Functional Machinery not otherwise classified J- 9 Jigs and Fixtures J-10 Parts of Functional Machinery
K INDUSTRY MACHINERY	K- 1 Processing K- 2 Construction K- 3 Petroleum K- 4 Steel Making K- 5 Farming K- 6 Household K- 7 Food Making K- 8 Textile and Clothing K- 9 Printing K-10 Industry Machinery not otherwise classified
L MAINTENANCE	L-1 Plant and Construction machinery and mechanical equipment of all kinds; also mobile equipment such as fleets of trucks, buses and taxicabs. L-2 Structures and other applications of arc welding in maintenance such as pipe lines, railroad tracks, bridge strengthening, etc., not covered under L-1.

Certification of Papers for Award

The following is a copy of the Jury of Award's certification announcing the numbers of the papers selected to receive awards in the $200,000 Industrial Progress Award Program:

First Grand Award—Paper No. 515—
"Welded Caissons for Naval Dry Docks";

Second Grand Award—Paper No. 223—
"Redesigned 40 MM. Anti-Aircraft Gun Carriage";

Third Grand Award—Paper No. 100—
"Arc Welding Builds Higher Efficiency Mercury Arc Rectifiers".

Of the Class A Awards, the following awards are made:

1st	2nd	3rd	4th
648	427	415	700

Of the A sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th
A-1	652	334	420	46
A-2	700	706	440	180
A-3	427	415	526	304
A-4	648	218	293	272

and Honorable Mention Awards as follows:

A-1	116				
A-2	102	378	245	496	448
A-3	566	372			
A-4	705	474	593		

Of the Class B Awards, the following awards are made:

1st	2nd	3rd	4th
708	730	558	469

Of the B sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th
B-1	469	424	653	247
B-2	708	730	558	513

and Honorable Mention to the following:

B-1	None
B-2	518

Of the Class C Awards, the following awards are made:

1st	2nd	3rd	4th
153	173	570	550

Of the C sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th
C-1	570	37	332	82
C-2	173	225	92	30
C-3	153	550	260	638
C-4	226	335	294	312

and Honorable Mention to the following:

C-1	120
C-2	None
C-3	None
C-4	None

Of the Class D Awards, the following awards are made:

1st	2nd	3rd	4th
305	508	147	240

Of the D sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th
D-1	305	508	147	540
D-2	240	67	417	60

and Honorable Mention to the following:

D-1	47	703	529	86	719	117	726
D-2	None						

Of the Class E Awards, the following awards are made:

1st	2nd	3rd	4th
515	698	155	555

Of the E sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th
E-1	549	452	33	709
E-2	698	555	48	521
E-3	580	739	431	437
E-4	515	155	193	204

and Honorable Mention to the following:

E-1	27	464	479				
E-2	510	694	14	136			
E-3	186						
E-4	517	443	71	418	651	275	409
	645	128	202	207	277	87	553
	243	361	492	536			

Of the Class F Awards, the following awards are made:

1st	2nd	3rd	4th
235	257	716	276

Of the F sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th
F-1	235	276	595	535
F-2	257	716	478	707

and Honorable Mention to the following:

F-1	114	359	
F-2	682	618	435

Of the Class G Awards, the following awards are made:

1st	2nd	3rd	4th
13	727	554	316

Of the G sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th
G-1	13	554	316	127
G-2	727	113	576	216

and Honorable Mention to the following:

G-1	556	617	451	314
G-2	125			

Of the Class H Awards, the following awards are made:

	1st	2nd	3rd	4th
	281	107	123	574

Of the H sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th
H-1	281	574	533	699
H-2	107	123	701	560

and Honorable Mention to the following:

H-1	208	481	406	362	350	244	704
	363	72	611	365			
H-2	191	69	678	484	88		

Of the Class I Awards, the following awards are made:

	1st	2nd	3rd	4th
	676	156	25	22

Of the I sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th
I-1	301	596	8	317
I-2	676	156	25	22

and Honorable Mention to the following:

I-1	76		
I-2	519	264	296

Of the Class J Awards, the following awards are made:

	1st	2nd	3rd	4th
	100	457	175	206

Of the J sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th
J-1	729	59	399	63
J-2	297	433	157	434
J-3	100	457	366	545
J-4	206	20	326	646
J-5	175	170	329	353
J-6	84	280	58	547
J-7	654	239	325	Vacate
J-8	462	83	410	614
J-9	45	439	221	634
J-10	471	591	196	367

and Honorable Mention to the following:

J-1	346	56	476	441	299
	338	198	583		
J-2	530	4	118	713	302
	590	604	470		
J-3	599	95	15		
J-4	None				
J-5	697	110	603	548	211
	507	49	612	425	39
	141				
J-6	29	139	702		
J-7	None				

Honorable Mention *(Continued)*

J-8	494	35	262	600	70
	666	261	143	172	400
J-9	622	449	624	633	126
	565	205	660	356	137
	79				
J-10	308	736	491	212	621
	5	466	423	91	482

Of the Class K Awards, the following awards are made:

1st	2nd	3rd	4th
223	185	539	532

Of the K sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th
K-1	539	373	405	569
K-2	532	187	259	99
K-3	561	426	23	527
K-4	185	347	105	459
K-5	154	413	50	66
K-6	551	650	159	64
K-7	288	150	723	516
K-8	543	655	16	220
K-9	564	282	562	514
K-10	223	217	454	291

and Honorable Mention to the following:

K-1	189	307	511	98	528	525	538
	149	200	336	659	248	331	103
K-2	93	266	340				
K-3	321	677					
K-4	10	279	442				
K-5	487	559	572	523	327		
K-6	395						
K-7	65	695					
K-8	None						
K-9	375						
K-10	287	402	573	44	379	541	349

Of the Class L Awards, the following awards are made:

1st	2nd	3rd	4th
531	419	649	267

Of the L sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th
L-1	419	267	658	534
L-2	531	649	416	112

and Honorable Mention to the following:

L-1	94	122	689	542	473	615	34
	354	687	68	460	453	342	53
	616	341	563	495	351	656	661
	711	552	219	12	444	450	1
	7	230	465	179	688	151	
L-2	414	571	333	36	480	214	62
	360	237	285	134	370	269	

Jury of Award

CHAIRMAN

DREESE, E. E., Head of Department of Electrical Engineering, The Ohio State University

JURORS

AHLQUIST, R. W., Assistant Professor of Electrical Engineering, Iowa State College

ANDERSEN, PAUL, Associate Professor of Structural Engineering, University of Minnesota

BUTTS, ALLISON, Professor of Electro-metallurgy, Lehigh University

DOWDELL, R. L., Professor of Metallography, University of Minnesota

DUKES, R. G., Professor Emeritus of Applied Mechanics, Purdue University

DWIGHT, H. B. Professor of Electrical Machinery, Massachusetts Institute of Technology

HOLTBY, FULTON, Assistant Professor, Mechanical Engineering Department, University of Minnesota

HUGHES, T. P., Assistant Professor of Mechanical Engineering and Assistant Superintendent of Shops in Mechanical Engineering, University of Minnesota

KOEPKE, C. A., Professor of Industrial Engineering, University of Minnesota

MACCONOCHIE, ARTHUR F., Professor of Mechanical Engineering, University of Virginia

MORRIS, CLYDE T., Professor of Civil Engineering, Ohio State University

MUCKENHIRN, O. W., Instructor in Electrical Engineering, University of Minnesota

TAYLOR, JACOB B., Professor and Head of Accounting, Ohio State University

VAN HAGAN, L. F., Professor, Chairman of the Department of Civil Engineering, University of Wisconsin

WRIGHT, CHILTON A., Professor of Hydraulic and Sanitary Engineering, Polytechnic Institute

In addition to the above Jurors, experts or outstanding authorities in the various classifications covered by the Program were consulted as needed in order to properly appraise the merits of the papers.

Studies in Arc Welding

Studies in Arc Welding

DESIGN, MANUFACTURE AND CONSTRUCTION

SECTION I
Automotive

Chapter 1—Low-Cost Grading and Hauling

By JOHN F. DILLON, JR.,

Welding Engineer LeTourneau Company of Georgia, Toccoa, Georgia

John F. Dillon, Jr.

Subject Matter: Construction by welding of a twin-Diesel-motored tractor, (400 horsepower), and scraper combination. Capacity of scraper is 60 yards and on a job moved clay for 5 cents per yard. A shovel and trucks cost 13 cents per cubic yard for same job. Aside from the motors and a few small parts, the unit was completely welded, including frame mounting for motors, fuel tanks, gears and gear case, transmission, oil pans and fuel and exhaust lines. The sequence of operations is thoroughly described. The cost of welded construction is much less than other methods. Considerable saving is made in weight.

A new 60-yard scraper had been built, but it was found that the single-motored tractor used in testing it did not have sufficient horsepower to give the scraper capacity operation. An idea was conceived to fabricate a twin-motored tractor that would develop 400 horsepower. It was decided to use two Diesel engines for the motive power, and connect them to the specially designed transmission by fluid drive. The transmission clutches, steering clutches, and power control unit were to be air-operated, but the reverse control was to be manually operated. Weeks of engineering, material preparation, arc welding, machining, and assembly were required for the first experimental model. A progressive discussion will be made on the fabrication of this tractor, followed by a cost per yard analysis of the tractor and scraper combination as compared with that of truck and shovel.

I. Main case sub-structure—The parts for this structure were torch-cut from special alloy, mild steel. The outside side plates were pre-heated to 1200°F and die-pressed to shape. Whenever possible, bearing blocks and

their bosses were welded as sub-structures before being set-up as part of the main sub-structures.

The structure was set up bottom-side up on a special jig, (See Fig. 1), with an allowance of 1/8 inch for shrinkage in the following manner:

Sequence of Operations

1. Position and tack weld top rim parts together. 2. Position and trim right and left side plate structures. 3. Position and clamp right and left bearing block plates and center partition. 4. Start shaft through right side plate. 5. Position bushing on shaft for right side plate. 6. Move shaft and position bushings for right inside plate and bearing block plate. 7. Move shaft and position bushing for center main partition plate. 8. Move shaft and position bushings for left bearing block plate and inside plate. 9. Move shaft and position bushing for left side plate. 10. Position, align and clamp right inside plate. 11. Align and clamp front right side partition structure. 12. Align and clamp center partition structure. 13. Align and clamp front left side partition structure. 14. Position, align and clamp left inside plate structure. 15. Position, align and clamp front plate. 16. Position and tack weld gussets between right inside plate and right side parti-

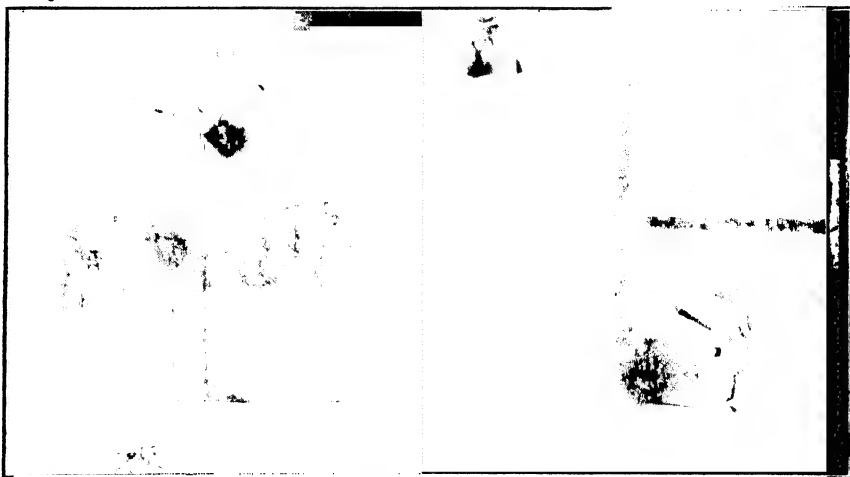



Fig. 1, (left). Structure bottom side up on special jig. Fig. 2, (right). Tack welding cross braces to structure.

tion plate. 17. Position and tack weld gussets between left inside plate and left side partition plate. 18. Check for alignment. 19. Tack weld parts together. 20. Position and clamp rear plate. 21. Align and tack weld rear plate to other parts. 22. Position, clamp and tack weld right spiral pinion front bearing block. 23. Position, clamp and tack weld right spiral pinion rear bearing block. 24. Position and lock tie plate. 25. Position, clamp and tack weld left spiral pinion front bearing block. 26. Position, clamp and tack weld left spiral pinion and take-off shaft bearing block. 27. Position and tack weld tie plate. 28. Position, clamp and tack weld right steering clutch shaft side bearing block. 29. Position, clamp and tack weld left steering clutch shaft side bearing block. 30. Position and tack weld channel to parts. 31. Position and tack weld angle to parts. 32. Position, clamp and tack weld support plates to right and left steering clutch bearing block. 33. Position, align and tack weld right and left side plates. 34. Position, clamp and tack weld right pinion bearing block. 35. Position and tack weld sections of right side plate. 36. Position, clamp and tack weld left pinion bearing block. 37. Position and tack weld section of left side plate. 38. Drag bead parts together using 1/4 inch electrode at 300 amperes. 39. Loosen clamps. 40. Position and tack weld top plate to structure. 41. Position and clamp rear plate. 42. Position and tack weld right and left side plates to structure. 43. Drag bead parts together. 44. Position, tack weld and drag bead bottom plate to structure. 45. Position, tack weld and drag bead main gear compartment bottom plates. 46. Position and tack weld hitch bottom with gussets. 47. Torch cut hole in

side plates. 48. Position and tack weld rings in holes. 49. Remove and raise structure to floor.

After the main case was removed from the set up jig, it was positioned on the floor for welding. Cross-braces were tack welded to the inside of the structure, (See Fig. 2), to help hold the warpage to a minimum. The structure was turned to a number of positions in order to make as many of the welds as possible in the flat, high-speed position. While the structure was in each position, additional drag beads were deposited to keep the structure from distorting. Several parts were positioned, tacked and welded during the fabrication of the structure due to the fact that welds would have been eliminated had these parts been set-up as part of the original structure. The structure was welded in eighty (80) man-hours by using 1/4-inch electrodes at 300 amperes and 5/16-inch electrodes at 400 amperes. All straight "tee" or "fillet" type welds were made in the flat position and the circular "tee" or "fillet" type welds were made in the horizontal or fillet position.

After the structure was completely welded, the crossbraces were removed, and it was found that very little distortion had taken place. The structure was welded in the following manner:

Sequence of Welding

1. Weld right and left side plates to bottom plate. 2. Weld main case rear plate to bottom plate 3. Weld right and left side plate sections to bottom plate. 4. Remove structure from jig; position on floor—bottom side up. 5. Tilt structure at 45°—left side up. 6. Weld right inside plate to bottom plate (outside). 7. Weld left side of hitch block to bottom plate. 8. Weld left side of left hitch gusset to bottom plate. 9. Weld left side of center and right hitch gussets to bottom plate. 10. Weld (inside) rim to right side plate. 11. Weld (outside) rim to left side plate. 12. Turn structure to 45° tilt—right side up. 13. Weld left inside plate to bottom plate (outside). 14. Weld right side of hitch block to bottom plate. 15. Weld right side of right hitch gusset to

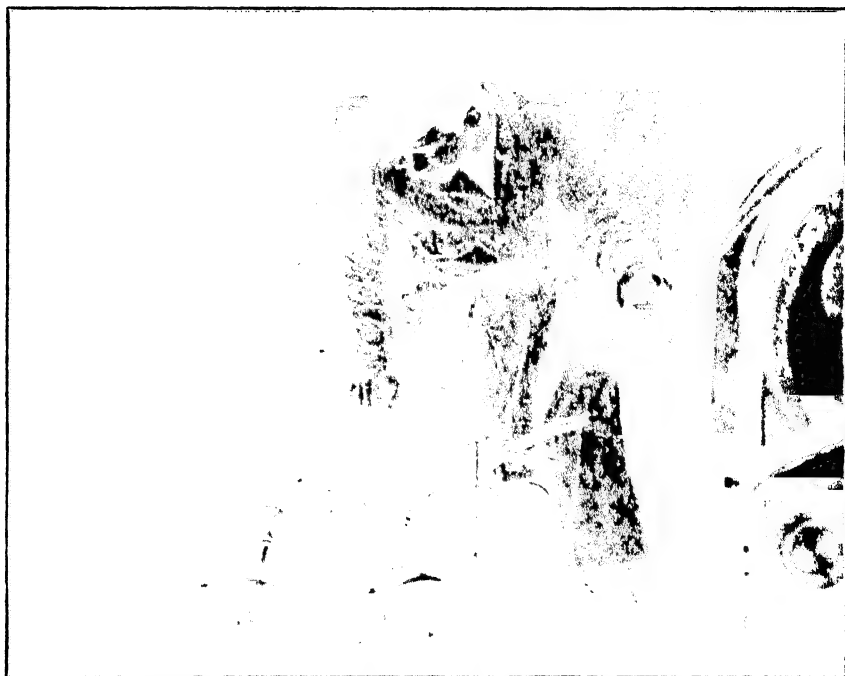



Fig. 3. Special boring jig for machining hard-to-reach places.

bottom plate. 16. Weld right side of center and left hitch gussets to bottom plate. 17. Weld (inside) rim to left side plate. 18. Weld (outside) rim to right side plate. 19. Turn structure to 45° tilt—rear side up. 20. Weld rear plate to bottom plate (outside). 21. Weld ends of main gear compartment bottom plates to bottom plate. 22. Weld bottom tie plate to right rear bearing block and front plate. 23. Weld rim (inside) to front plate. 24. Turn structure 45°—structure upright with rear plate up. 25. Position and tack weld front channel parts to front plate. 26. Weld upright channel parts to long channel. 27. Weld upright channels to partition plates. 28. Weld bottom of long channel to front plate. 29. Weld pinion gussets to right and left side plates. 30. Turn structure to 45° tilt—front side up. 31. Weld front plate to bottom plate and main gear compartment bottom plates. 32. Weld rim (inside) to main rear plate. 33. Weld rim (inside) to side parts of main rear plate. 34. Weld rim (outside) to front plate. 35. Turn structure 45°—front plate up. 36. Drag bead parts together. 37. Weld section of right and left side plate rim parts together. 38. Weld front plate to right and left side plates. 39. Weld front of hitch block to bottom plate. 40. Weld front side of bottom gussets to right and left pinion blocks. 41. Turn structure 90°—top of structure up. 42. Torch cut PCU rear plate. 43. Weld rim parts together. 44. Weld right and left front partition gussets to angle. 45. Weld rear plate to back section of rim. 46. Weld rear plate side sections to bottom plate (inside). 47. Raise structure on right side. 48. Drag bead parts to bottom plate. 49. Tilt structure 45°.

50. Weld left side plate sections together. 51. Weld left side plate section to rear plate. 52. Weld left side plate to rear plate. 53. Weld right side plate (inside) to main rear plate. 54. Weld gusset to left pinion bearing block. 55. Weld gusset to left front partition structure. 56. Weld left front partition to front plate. 57. Weld tie plate to left front spiral pinion blocks. 58. Weld left spiral pinion tie plate to front plate. 59. Weld left and center front upright channels to front plate. 60. Weld center partition to front plate. 61. Weld side of channel to center partition. 62. Weld tie plate to right rear spiral pinion block and front plate. 63. Weld front and rear spiral pinion blocks to right and front partition. 64. Weld right front upright channels to front plate. 65. Weld side of channel to right front partition. 66. Weld gussets to right inside plate. 67. Weld side of channel to right inside plate. 68. Weld right side plate (inside) to front plate. 69. Weld front long channel to right side plate. 70. Weld right pinion block gusset to right side plate. 71. Tilt structure to 45°—front plate up. 72. Weld (inside) right side plate to rear plate. 73. Weld gusset to left pinion block. 74. Weld left inside plate to rear plate. 75. Weld left steering clutch bearing block to rear plate. 76. Weld center partition to rear plate. 77. Weld right inside plate to rear plate. 78. Weld right side plate section to rear plate (inside). 79. Weld pinion block gusset to right side plate. 80. Weld front gusset to left inside plate. 81. Weld gussets to left front partition plate. 82. Weld side of channel to left front partition plate. 83. Weld left front and rear spiral pinion blocks to tie plates. 84. Weld side of channel to center partition. 85. Weld right front and rear spiral pinion blocks to right partition. 86. Weld side of channel to right front partition plate. 87. Weld gussets to right inside plate. 88. Weld side of channel to right inside plate. 89. Weld bottom pinion block gusset to right side plate. 90. Turn structure back 45°—structure upright with left side up. 91. Weld (outside) left side plate to main gear compartment bottom plate. 92. Weld gussets to hitch block. 93. Weld (outside) right inside plate to main gear compartment bottom plate. 94. Weld (outside) ring to left side plate. 95. Weld (outside) left side plate to top and bottom plates. 96. Weld (inside) ring to right side plate. 97. Weld (inside) right side plate to top and bottom plates. 98. Weld (inside) left inside plate to main gear compartment bottom plate. 99. Weld angle to side of left front partition plate.

100. Weld lip of left and center upright channel. 101. Weld side of left and center upright channels to long channel and side of left front and center partition plates. 102. Weld angle to left steering clutch bearing block; center partition, right steering clutch bearing block, right front partition and right inside plate. 103. Weld bottom spiral pinion to plate to left tie plate and to right partition plate. 104. Weld side of right upright channel to right front partition and long channel. 105. Weld right side plate (inside) to right main gear compartment bottom plate. 106. Weld sides of long channel to right side plate. 107. Weld bottom side of right pinion block to right side plate. 108. Weld bottom gusset to right pinion block. 109. Weld right pinion block to right side plate. 110. Torch cut, hole; position, tack weld and weld pipe to right and left steering clutch block supports. 111. Tilt structure 45°—bottom of structure going down. 112. Weld left inside plate to bottom plate and end of channel. 113. Weld left front partition to bottom plate. 114. Weld channel to side of left front partition. 115. Weld left spiral pinion blocks to top of left front partition. 116. Weld side of left steering clutch block to bottom plate. 117. Weld left support plate to side left steering clutch block. 118. Weld side of center partition to bottom plate. 119. Weld channel to side

of center partition plate. 120. Weld side of right steering clutch block to bottom plate. 121. Weld left support plate to side of right steering clutch block. 122. Weld side of right front partition plate to bottom plate. 123. Weld channel to side of right front partition plate. 124. Weld top of right pinion bearing block to side plate. 125. Weld right inside plate to bottom plate. 126. Raise structure on left side—right side up. 127. Drag bead parts to bottom plate. 128. Tilt structure 45°. 129. Weld right side plate sections together. 130. Weld right side plate section to rear plate. 131. Weld right side plate to rear plate. 132. Weld left side plate (inside) to main rear plate. 133. Weld gusset to right pinion bearing block. 134. Weld gusset to right front partition structure. 135. Weld right front partition to front plate. 136. Weld tie plate to right front spiral pinion block. 137. Weld right spiral pinion tie plate to front plate. 138. Weld right and center front upright channels to front plate. 139. Weld center partition

Fig. 4. Mill used for bulk of boring.

to front plate. 140. Weld side of channel to center partition. 141. Weld tie plate to left rear spiral pinion block and front plate. 142. Weld front and rear spiral pinion blocks to left front partition. 143. Weld left front partition to front plate. 144. Weld left front upright channels to front plate. 145. Weld side of channel to left front partition. 146. Weld gussets to left inside plate. 147. Weld side of channel to left inside plate. 148. Weld left side plate (inside) to front plate. 149. Weld front long channel to left side plate.

150. Weld left pinion block gusset to left side plate. 151. Tilt structure to 45°—front plate up. 152. Weld (inside) left side plate to rear plate. 153. Weld gusset to right pinion block. 154. Weld right inside plate to rear plate. 155. Weld right steering clutch bearing block to rear plate. 156. Weld center partition to rear plate. 157. Weld left inside plate to rear plate. 158. Weld left side plate section to rear plate (inside). 159. Weld pinion block gusset to left side plate. 160. Weld front gusset to right inside plate. 161. Weld gussets to right front partition plate. 162. Weld side of channel to right front partition plate. 163. Weld right front and rear spiral pinion blocks to tie plate. 164. Weld side of channel to center partition plate. 165. Weld left front and rear spiral pinion blocks to left partition plate. 166. Weld side of channel to left front partition plate. 167. Weld gussets to left inside plate. 168. Weld side of channel to left inside plate. 169. Weld bottom pinion block gusset to left side plate. 170. Turn structure back 45° structure upright with right side up. 171. Weld (outside) right side plate to main gear compartment bottom plate. 172. Weld gussets to hitch block.

173. Weld (outside) left inside plate to main gear compartment bottom plate. 174. Weld (outside) ring to right side plate. 175. Weld (outside) right side plate to top and bottom plates. 176. Weld (inside) ring to left side plate. 177. Weld (inside) left side plate to top and bottom plates. 178. Weld (inside) right inside plate to main gear compartment bottom plate. 179. Weld angle to side of right front partition plate. 180. Weld lip of right center upright channel. 181. Weld side of right and center upright channels to long channel and side of right front and center partition plates. 182. Weld angle to right steering clutch bearing block, center partition, left steering clutch bearing block, left front partition and left inside plate. 183. Weld side of left upright channel to left front partition and long channel. 184. Weld left side plate (inside) to left main gear compartment bottom plate. 185. Weld sides of long channel to left side plate. 186. Weld bottom gusset to left pinion block. 187. Weld bottom side of left pinion block to left side plate. 188. Weld left pinion block to left side plate. 189. Weld pipe to right and left steering clutch supports. 190. Tilt structure 45°—bottom of structure going down. 191. Weld right inside plate to bottom plate and end of channel. 192. Weld right front partition to bottom plate. 193. Weld channel to side of right front partition. 194. Weld right spiral pinion blocks to top of right front partition. 195. Weld side of right steering clutch block to bottom plate. 196. Weld right support plate to side of right steering clutch block. 197. Weld side of center partition to bottom plate. 198. Weld channel to side of center partition plate. 199. Weld side of left steering clutch block to bottom plate.

200. Weld right support plate to side of left steering clutch block. 201. Weld side of left front partition plate to bottom plate. 202. Weld channel to side of left front partition plate. 203. Weld top of left pinion bearing block to side plate. 204. Weld left inside plate to bottom plate. 205 Turn structure at 45° tilt—rear side up. 206. Weld rear plate to top plate. 207. Weld top plate to rim. 208. Weld side plates to top plate. 209. Weld (inside) bottom plate to main rear plate. 210. Weld rear side of angle to bottom plate. 211. Weld rear end of right and left front partition plates to angle. 212. Weld left side of channel to bottom plate. 213. Weld left and right inside plate gusset to top of channel. 214. Weld right front spiral pinion block to bottom tie plate. 215. Weld rear side of left rear spiral opinion block to bottom plate. 216. Weld bottom plate to front plate (inside). 217. Weld right and left main gear compartment bottom plate to front plate (inside). 218. Weld top of front long channel to front plate. 219. Weld top of all partition plates to front plate. 220. Turn structure to 45° tilt—front up. 221. Weld right front and rear spiral pinion blocks to bottom tie plate. 222. Weld front side of channel to bottom plate. 223. Weld front side of right and left inside plate gussets to top of channel. 224. Weld front side of angle to bottom plate. 225. Weld front end of right and left steering clutch bearing blocks to angle. 226. Weld front side of right and left inside plate gusset to angle. 227. Weld main rear plate to bottom plate (inside). 228. Weld right and left main gear compartment bottom plate to bottom plate. 229. Weld top of all partition plates to rear plate. 230. Turn structure—top up. 231. Position, tack weld and weld 3 sides of right and left top bearing block gussets. 232. Position and tack weld upper hitch reenforcing plates. 233. Weld front upper hitch reenforcing plate to bottom plate and top of center partition. 234. Weld structure on right side—structure upright. 235. Weld upper hitch reenforcing plates together. 236. Weld left upper hitch side plate to rim and bottom plate. 237. Turn structure 180° —left side up—structure upright. 238. Weld upper hitch reenforcing plates together. 239. Weld right upper hitch side plate to rim and bottom plate. 240. Aside structure.

The case was then taken to the furnace to be annealed. It was heated to 200° F and allowed to cool slowly for twenty-four hours. The case was then sent to the cleaning department where it was sand blasted to remove the scale and dirt from it. After this, the structure was sent to the machine shop to be faced, bored, drilled and tapped.

A special boring jig, (See Fig. 3), was required for machining places that the regular boring mill could not reach. This machining operation required seventy (70) man hours. The balance of the boring was done in an additional forty-eight (48) hours on the regular mill, (See Fig. 4). It was then removed to the drill where it was completely drilled and tapped in seventy-two (72) hours.

The case was transported to the assembly line for further operations.

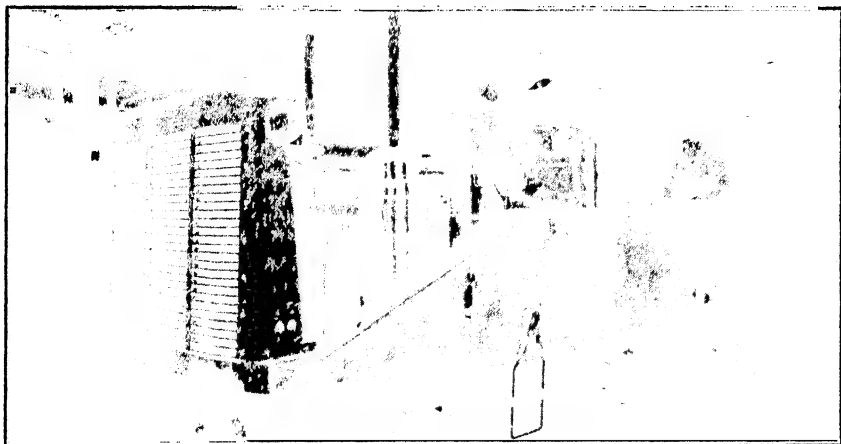



Fig. 5. Structure ready for assembly.

II, Motor Frame Structure—This structure has a three-fold purpose—firstly, the right and left tanks are fuel tanks with 155-gallon capacity; secondly, the crossbeam and center beam serve as air storage tanks; thirdly, the group when welded together serve as beam supports for the two, 200 horsepower Diesel engines. The tanks act as cantilever beams and therefore were welded rather securely by welding the ends of the right and left fuel tanks and the center air tank to the main case.

Before setting up and welding the motor frame structure, the four tanks were set up and welded as sub-structures. The following routine and welding specifications apply to the left fuel tank.

Sequence of Operations

1. Buff all inside surfaces of parts. 2. Position left side tank plate on table. 3. Position, tack weld and weld baffle plates (side) to outside plates (stagger welds). 4. Weld top end of baffles to top part of side plate. 5. Position and tack weld right side tank plate. 6. Turn structure 90°—top side up. 7. Weld bottom end of baffles to bottom part of side plate. 8. Turn structure 90°—left side up. 9. Weld side of baffles to right side plate. 10. Torch cut all holes for pipe sleeves. 11. Position, tack weld and weld pipe fittings to tank. 12. Position, tack weld and weld pipe fitting guard to bottom of tank. 13. Position tank upright. 14. Weld seam of top plate. 15. Weld both end plates to bottom plate. 16. Turn structure 90°—left side up. 17. Weld both end plates to right side plate. 18. Turn structure 90°—bottom up. 19. Weld both end plates to top plate. 20. Turn structure 90°—right side up. 21. Weld both end plates to left side plate. 22. Raise structure (top up) to 45° tilt. 23. Weld edge of right side plate to top plate. 24. Raise front part of structure until top plate edge is level. 25. Weld rest of right side plate to top plate. 26. Turn structure 180°—bottom plate edge level. 27. Weld left side plate to bottom plate. 28. Aside structure.

A very similar procedure is followed in fabricating the right fuel tank. Inside, at the center of both fuel tanks, a baffle plate was welded in. This plate also acts as a web plate to reduce the diaphragming action of the side plates.

The crossbeam structure, in addition to serving as an air tank, also forms a base for the support of the radiators. The set-up and welding procedure with its welding specifications is as follows:

Sequence of Operations

I. Set Up—1. Position bottom plate on set up table. 2. Position spacer; position top plate. 3. Position front plate. 4. Tack weld parts together. 5. Remove spacer; a side structure.

II. Weld—1. Position structure on front plate at 45° tilt. 2. Weld top plate to rear plate. 3. Weld top plate to front plate. 4. Turn structure over. 5. Weld (complete) bottom plate to front plate. 6. Turn structure over. 7. Weld (fill in skips) top plate to rear plate. 8. Weld (fill in skips) top plate to front plate. 9. Position structure flat; drill holes in top plate. 10. Turn structure over; drill holes in bottom plate. 11. Position tack weld and weld ends of stay bolts to bottom plate. 12. Turn structure over; weld ends of stay bolts to top plate. 13. Torch cut hole; tack weld and weld coupling in top plate. 14. Position structure on front plate. 15. Torch cut holes in rear plate. 16. Position, tack weld and weld couplings to rear plate. 17. Drill and top hole in bottom plate. 18. Clean track out of structure. 19. Position and tack weld end plates. 20. Weld end plates to front plate. 21. Turn structure 90°; weld end plates to bottom plate. 22. Turn structure 90°; weld end plates to rear plate. 23. Turn structure 90°; weld end plates to top plate. 24. Aside structure.

The center beam is used as additional air storage space, and it adds also to the structural strength of the frame. The inside, rear motor bolt plates are anchored to this beam. The beam was constructed by welding two angles together to form a box beam. And by the following procedure was made into the finished tank sub-structure:

1. Raise rear end of beam 45°. 2. Position, tack weld and weld 1st side of plate inside end of beam. 3. Turn structure at 90° intervals and weld other 3 sides of plate. 4. Position beam; position and tack weld reenforcing plate to bottom of beam. 5. Position and tack weld temporary braces to reenforcing plate. 6. Tilt structure until reenforcing plate is up and at 45°. 7. Weld 1st side of reenforcing plate to bottom of beam. 8. Turn structure 90°—2nd side of reenforcing plate up at 45°. 9. Weld 2nd side of reenforcing plate to bottom of beam (stagger with opposite side). 10. Aside structure.

Sequence of Operations

The oil pan guards are welded as sub-structures because they can be positioned more easily due to their size and at the same time better quality welds result. The following procedure was used for welding:

I. Set Up—1. Position bottom plate. 2. Position and tack weld side plates. 3. Aside structure.

II. Weld—1. Position structure; weld front of right side plate to bottom plate. 2. Position structure; weld rear of right side plate to bottom plate. 3. Position structure at 45°—right edge up. 4. Weld right side plate to bottom plate. 5. Position structure; weld front of left side plate to bottom plate. 6. Position structure; weld rear of left side plate to bottom plate. 7. Position structure at 45°—left edge up. 8. Weld left side plate to bottom plate. 9. Aside structure.

Sequence of Operations

Having these sub-structures completed, they were positioned, tacked and welded together to make the motor frame structure as outlined below:

1. Position align fuel tanks. 2. Position front air tank. 3. Align and tack weld parts together. 4. Position and tack weld center air tank. 5. Position and tack weld temporary braces. 6. Position and tack weld battery bottom cross beams. 7. Position and tack weld cross pipe to fuel tanks. 8. Weld (inside) center air tank to front air tank. 9. Position and tack weld end cap to center tank. 10. Weld top of cap to center tank. 11. Weld bottom of cap to center tank and top of front tank. 12. Weld right and left sides of center tank to front tank. 13. Weld top of right tank to front tank. 14. Weld right tank to end of front tank. 15. Weld left tank to end of front tank. 16. Weld top of left tank to front tank. 17. Turn structure on side of left fuel tank. 18. Weld left fuel tank to front air tank (bottom and rear). 19. Weld center air tank re-enforcing plate to rear of front air tank. 20. Weld cross pipe to left tank. 21. Position and tack weld vertical beam to left fuel tank. 22. Position, tack weld and weld (sides) caps to vertical beam. 23. Weld top of bottom cap to vertical beam. 24. Weld bottom of top cap to vertical beam. 25. Weld vertical beam (sides and bottom end) to fuel tank. 26. Weld battery box cross beams to left fuel tank (all around). 27. Weld right tank to end of front air tank. 28. Turn tank 180° on side of right tank. 29. Weld right fuel tank to front air tank (bottom and rear). 30. Weld center air tank reenforcing plate to rear of front air tank. 31. Weld cross pipe to right tank. 32. Position and tack weld vertical beam to right fuel tank. 33. Position, tack weld and weld (sides) caps to vertical beam. 34. Weld top of bottom cap to vertical beam. 35. Weld bottom of top cap to vertical beam. 36. Weld vertical beam (sides and bottom

end) to fuel tank. 37. Weld battery box crossbeams to right fuel tank (all around). 38. Weld left tank to end of front air tank. 39. Turn structure 90°—bottom up. 40. Position and tack weld bottom plate. 41. Weld sides of bottom plate to fuel tanks. 42. Weld ends of right and left tank to bottom of front air tank. 43. Turn structure over—top side up. 44. Weld (stagger beads on opposite sides) center tank reenforcing plate to bottom plate. 45. Aside structure.

It is to be noted in the procedure above that the front end of the center air tank is fitted over the front tank and then welded, through the open end and on the sides. A hole in the bottom plate of the center air tank fits around a sleeve welded in the front tank, and when welded to this sleeve, the joint is air tight. The weld on the outside joining the tanks together is also made air tight. After the structure is completely welded, the tanks are tested with 80 pounds of air.

The motor frame structure was next aligned and welded to the case structure with the weld specification as listed:

Sequence of Operations

1. Position, align and tack weld motor frame structure to case. 2. Weld top of fuel tanks to case. 3. Weld sides of fuel tanks to case. 4. Weld bottom of fuel tanks to case. 5. Weld top of center air tank to case. 6. Weld sides of center air tank to case. 7. Weld bottom of center air tank to case.

The structure as fabricated up to this point is ready for assembly and finishing, (See Fig. 5). As connected with the motor frame, it includes mounting radiators, welding battery boxes in place, bolting dash on case, mounting motors and connecting them to air-filters, and radiators, wiring for the starter and head lights, and mounting of the hoods. But before this work could be done several more sub-structures had to be welded and then sub-assemblies made.

Fig. 6. Dash made of 12-gauge mild steel.

Radiator—This structure is composed of three sections welded as sub-structures and then bolted together with the radiator web (purchased part).

The radiator top tank has a large die pressed shell made of special alloy mild steel and several torch cut parts welded to it. The following procedure applies to this structure:

Sequence of Operations

I. Set Up—1. Position bolt plate on jig. 2. Position top curved section. 3. Position back plate. 4. Align and tack weld parts together. 5. Position and tack weld side filler plates. 6. Weld (inside) top curved section to bolt plate. 7. Position and tack weld temporary reenforcing bar. 8. Remove and aside structure.

II. Weld—1. Position structure at 45° tilt—edge of back plate and bolt plate up. 2. Weld edge of back plate to bolt plate. 3. Weld back plate (while turning structure) to top section. 4. Weld bolt plate (outside) to top section. 5. Turn structure on front side—raise left side 45°. 6. Weld back plate (right end) to top section. 7. Turn structure until right side is up to 45° tilt. 8. Weld back plate (left end) to top section. 9. Turn structure on top side. 10. Weld bolt plate to straight part of top section. 11. Turn structure until left side is up at 45°. 12. Weld bolt plate to straight part of top section. 13. Position structure on right side. 14. Weld (outside) left filler plate to top section. 15. Weld (inside) right filler plate to top section. 16. Turn structure end for end. 17. Weld (outside) right filler plate to top section. 18. Weld (inside) left filler plate to top section. 19. Position structure on front side. 20. Position, tack weld and weld intake pipe. 21. Position, tack weld and weld connection pipe. 22. Aside structure.

Fig. 7. Deck cover plate bolted to top of case.

Sequence of Operations

The side sections are composed mainly of a die-pressed shell. The die used for this pressing was arc welded and the letters "Tournapull" were built up on the die with hard facing. The welding procedure is as follows:

I and II. Set Up and Weld—1. Position side plate; position jig inside. 2. Position and tack weld bottom bolt plates. 3. Position and tack weld top bolt plate. 4. Remove jigs; turn structure over. 5. Position and tack weld filler plates. 6. Weld filler plates together. 7. Weld filler plate to side plate. 8. Weld (outside) bottom bolt plate to outside of side plate. 9. Turn structure over; weld (inside) filler plate to side plate. 10. Position structure on bottom end. 11. Weld top (outside) of top bolt plate to side plate. 12. Weld (inside) filler plates together. 13. Weld bottom filler plate (inside) to side plate. 14. Weld top side of bottom bolt plates to side plate. 15. Weld outside bottom bolt plate to side plate. 16. Turn structure end for end. 17. Weld bottom of bottom bolt plate to side plate. 18. Weld (outside) small filler plate to side plate. 19. Weld bottom of top bolt plate to side plate and filler plate. 20. Aside structure.

The welded parts were assembled together with bolts. Two radiator assemblies are required for each tractor—one for each engine. The base bolt plates were bolted to the bottom of the radiators and each structure positioned and aligned on the cross beam air tank. The base bolt plates were tacked to the tank and then the radiator structures were removed after which the plates were welded to the tank.

The motor base, bolt plates along with their gussets are aligned by means of a special jig. This jig has a shaft which goes through the drive shaft openings in the front of the case, thus corresponding to the line shaft of the motor and coupling shaft. The bolt plates are welded into position after the jig is removed.

The battery boxes were made from pieces of 12-gage mild steel and arc welded together. They were then tack welded to the cross beams provided for them just in front of the case. The covers were made of the same kind of material as the body of the boxes.

A dash, (See Fig. 6), was made of 12-gage mild steel with a 1x1x$\frac{3}{16}$-inch angle welded around the upper edge and a 1x1x$\frac{1}{4}$-inch angle welded to the bottom for a bolt plate. This structure was bolted to an angle welded between the fuel tanks next to the rim of the case structure. All gages, meters, indicators, speedometers, starters and light switches were mounted to this structure. There are two complete sets—one for each motor. The welding procedure used is as follows:

Sequence of Welding

1. Position plate. 2. Position and tack weld top band. 3. Turn plate over; position and tack weld angle to plate. 4. Turn structure over—top band up. 5. Weld front of plate to top band. 6. Weld front of plate to angle. 7. Turn structure over. 8. Weld angle to back of plate. 9. Weld (edge) top band to plate. 10. Grind top edge. 11. Aside structure.

The radiators were rebolted to the base plates. An anchor beam for the radiator grill and hood was constructed between the radiators. It consisted of one vertically positioned box beam welded to the top of the center tank and a box beam brace welded to the top of the vertical beam running diagonally backward with the other end welded to the center tank. A curved piece was welded to the top of the box beam frame in line with the radiator tops. Similarly curved pieces were welded to the radiator tops at their centers and overlapping the curved piece on the box beams to which it was bolted. This completed the radiator top.

The radiator grills were next bolted to each outside radiator side plate and the center beam, thus forming the radiator front as shown in Fig. 5. These grills were arc welded structures, being fabricated before assembly to the front of the radiators.

Before bolting the motors in position, the oil pan guards were welded to the bottom motor frame plate. A box beam was welded to the center tank immediately in front of the battery boxes. To the top of this beam was welded a bracket which supports the filter tank for the transmission case oil. The throttle control bracket was mounted between the battery boxes and the filter tank support.

The motors were then aligned, shimmed and bolted in the proper position. Brackets for the air filter tanks were welded towards the front end of the incline plate of each fuel tank. Hose connections were made from the compressor to the filter tank and then to the storage tank. After this, the radiator hose connections were made to the motor. Next, the exhaust pipes were connected to the motors. They are seen as the vertical pipes behind

Fig. 8. Bolting tire to wheel.

the radiators in Fig. 5. Also welded to the structure at this point, was the hinged step to the side of the left fuel tank as seen in Fig. 5.

The hood was made of three separate structures.

The left side structure was made of two pieces of 12-gage material butt welded together. This seam was reinforced by welding a 1x1x3/16-inch angle to each section of 12-gage material just to the sides of the butt weld. This angle also helped to add stiffness to the structure. Two rolled sections of 1/4x1 1/4-inch bar were welded to the front and rear of the structure to be later drilled and tapped for bolting the hood to the radiator tops and the top of the dash. A standard 1/2 pipe section was welded to the front lower edge of the main sheet to improve appearance as well as reinforcement. A short length of 1x1x3/16-inch box beam was welded to the rear lower edge of the main sheet, also for reinforcement. Another 1x1x3/16-inch angle was welded to the underside of the 12-gage material for added stiffness The right side structure was similarly constructed except that instead of butt welding the 12-gage sections together, short sections of 1/4-inch pipe were welded to each edge and staggered so that they interlocked when the edges were placed together. These hood structures were bolted on after the rest of the motor assembly was done.

Assembly of Transmission in Case—The transmission was assembled as shown in Fig. 6. The hydraulic oil manifolds were assembled and installed to the case before starting the installation of the gears and so forth. To begin with, the right and left spiral pinion gears were installed in the front of the case and adjusted. The gears for the power control unit were assembled to the shaft at the same time as that of the left spiral bevel pinion. The line shaft for the power control unit was installed in the case and extends through the entire length of the case. The power control unit was assembled in its case at the rear of the main case. After this installation of gears and and clutches, the rear cover plate (an arc welded sub-structure) was bolted on and then the cable drums were assembled to their shafts on the outside of

the cover plate. The right and left final drive pinions were assembled to their shafts with the bearings. The assembled pinion shafts were installed in each rear corner of the case. Next, the right and left final drive bull gears were assembled to their shafts with the bearings and oil seals. This assembly was then installed in the center of the right and left sides of the case.

An assembly for the primary shaft was made. This consisted of mounting the high speed primary gear on the shaft with its female clutch cones and bearings. Similarly, the low speed primary gear was mounted. These gears were locked in place on the shaft by nuts. Then the male clutch cones were assembled to the shaft and afterwards the cam rings, adjusting spiders, and throwout collars. The primary low speed driven gear was assembled to the secondary shaft. Then the reverse driving gear, the secondary high driving gear with its female clutch cone and adjusting spiders, cam rings, throwout yoke collar, a roller bearing and adjusting nut were assembled to one side of the shaft. On the other side of the shaft the primary high driven gear, the secondary low-driving gear with its female gear clutch cone and ball bearing assemblies, and the male cone, adjusting spider, cam ring, throwout yoke collar and a roller bearing were assembled.

The steering clutch shaft was assembled next. The reverse dog clutch gear was assembled to the shaft, then the adjusting roller bearings on the reverse driven gear. Following this, the reverse shifting dog clutch was assembled along with the secondary low driven gear and a roller bearing. After this one steering clutch assembly and brake band which consists of a male and female inner and outer cone spline driven, an adjusting spider, cam rings and throwout yoke assembly were assembled to one side of the shaft. On the other side the secondary high driven gear and roller bearing were assembled, then a steering clutch assembly similar to that on the other side.

The primary shaft assembly was installed in the front part of the case just behind the spiral bevel pinions. Along with this installation, mounting brackets were welded in place for the hydraulic pumps on the primary shaft. All bearing adjustments were then made. The secondary shaft was installed just behind the primary shaft and all adjustments made on the bearings and nuts. The steering clutch shaft was next installed and after making adjustments, the steering clutch female cones were bolted to the final drive pinion flanges which completed the drive from the hydraulic coupling to the axles.

The air control shifting mechanism and all necessary air pipes, valves and cylinders were installed in the case. Also the lubricating oil line connections were made thus completing the inside installation.

The deck cover plate was assembled next. This consisted of mounting the air line pipes and valves in the air-control console and then bolting it to the cover plate. Additional pipe lines were clamped to the under side of the deck and connected to the console pipes. The plate was then bolted to the top of the case, (See Fig. 7). The seat was assembled to the rear of the console and the rear hitch ball block was bolted to the rear edge of the case. Air cylinders were connected along with the brake assembly previously installed in its housing under the deck plate. A compression release lever valve assembly was bolted to the side of the console and the foot pedal throttle controls were installed.

After checking all installations, the drive couplings were bolted in, connecting the motors with the transmission. Then the oil seal retainer plates were aligned to each side of the case at the center prior to bolting two assembled tires and wheels (See Fig. 8). The wheels are all welded

structures. The wiring connections were completed, the hood bolted on, two hundred and twenty (220) gallons of 000-DA lubricating oil was put in the transmission case. Nineteen (19) gallons and three (3) quarts of water for each motor was put in the radiators and then one hundred and fifty-five (155) gallons of fuel oil put in the tanks. The motors were started and when the air pressure built up, the unit was tested.

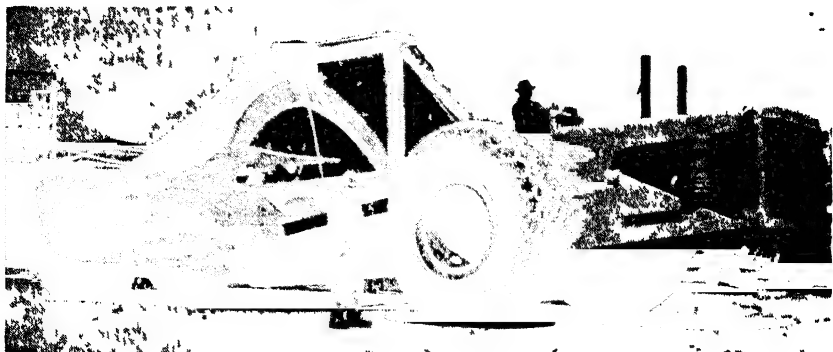



Fig. 9. Tractor assembled with 60-yard scraper.

The final drive gears (See Fig. 10), the clutch cones, the throwout yoke structures and the smaller gears are all welded structures. Some few parts of these structures are sand cast and there are immediate future plans for casting some of the smaller gears, which type of production is more economical. The copper linings in the female clutch cones and steering clutch cones are tack welded in with tacks ½-inch long on one inch centers.

Conclusion—In Fig. 9, the tractor is shown assembled to the 60-yard scraper. This combined unit is 52 feet long, 14 feet 8 inches wide (the scraper governs) and 13 feet 9½ inches high (scraper governs) and weighs 95,990 pounds. The units are shipped separately, due to the size of each The scraper is bolted together—designed this way so that it could be broken down to its welded structures for shipping. The tires are inflated with forty-five (45) pounds of air and are thirty-four (34) ply.

The tractor as a single unit cannot move under its own power, due to the over-hang of the weight in front and the fact that there are only two wheels. But there are very few occasions when the unit is detached from the scraper unit. Connected to the scraper, the steering is accomplished by applying brakes to one wheel, thus causing the unit to turn to the same side that the wheel is on A non-stop U-turn requires only an 86 foot circle Again referring to Fig. 7, the two center levers on the console control the steering clutches.

The depth of cut can be adjusted up to a maximum of 14 inches and the depth of spread up to 35 inches. This operation is accomplished by the power control unit on the rear of the case-connection being made by cable to the scraper through sheave housings. The two right levers on the console control the operation of the power control unit.

The speed of the tractor is controlled by the two left levers on the console. Remember the levers control these operations by air working under pressures of 85 to 105 pounds per square inch and the air being supplied by two compressors each compressing 14.5 cubic feet per minute.

The motors are connected to the transmission case by fluid drive. This

feature gives better performance by reducing shock loads to the transmission and smoother operation. Should one motor fail to operate, the remaining motor can run the unit at a slow speed if it is turning between 500 and 700 revolutions per minute (400 revolutions per minute being the minimum for either motor to work) and at the same time the dead motor will not turn over.

The tractor has performed beautifully with the 60-yard scraper. With just the tractor pulling the scraper, 40 yards of clay soil (2500 pounds per yard) were scooped up, and with a pusher on behind, 59 yards, constituting a heaped and capacity load, were scooped up. When attached to a 45-yard capacity scraper, the tractor increased the pick-up load (without pusher) by 10 yards, almost loading the scraper to capacity. Fig. 11 shows the tractor and the 60-yard scraper in operation. (See also Figs. 12, 13, 14, 15 and 16).

There seems to be no question about the fabrication of the tractor by arc welding being more economical than by other methods. It is true that the smaller gears, clutch cones and similarly sized parts can be cast cheaper if the foundry is running better than a 40 per cent yield. Yet, to cast the case would be a very difficult job and at the same time would require quite an expense for making the patterns and setting up the molds. Many odd-shaped parts were accomplished easily and quickly by arc welding simple parts together.

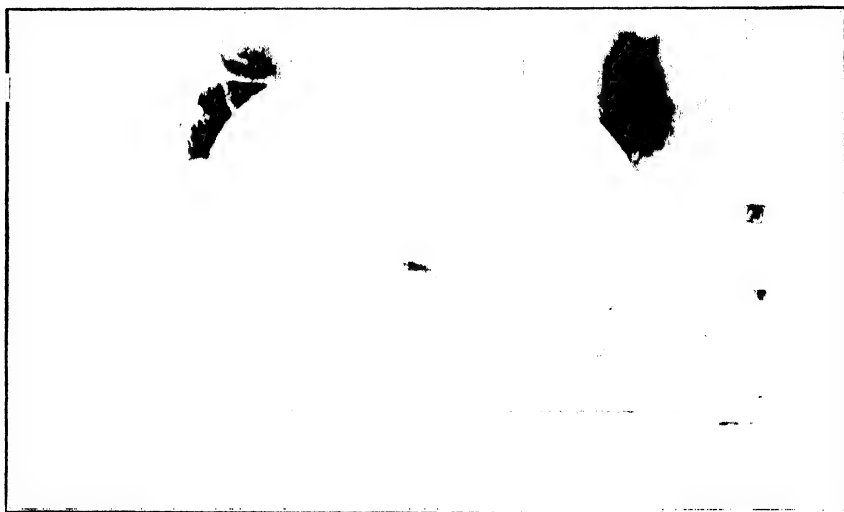



Fig. 10. Arc welding the drive gears.

Of more interest to a contractor doing grading work is the cost for moving and grading each yard of earth. The initial equipment cost is an important item but profit is based on the operating cost per yard moved. Therefore, an analysis will be made on the cost per yard as accomplished by the tractor and scraper with a pusher (bulldozer) added and finally by a $2\frac{1}{2}$-yard shovel, five-yard dump trucks and a pusher for leveling. Records were kept on an actual grading job in which clay soil was handled. The job was done by the tractor and the 60-yard scraper, so that fairly accurate figures can be given.

In the first case, the tractor and scraper not only scoop up the load,

but also level it when dumped, thus eliminating the expense of a bulldozer. The depreciation of the equipment will be figured on 3 cents per $1000 invested, based on a 10,000 hour straight-line write-off. The list price of the tractor and scraper is $46,270. At 3 cents per $1000, the depreciation amounts to $1.38 per hour. The operator for the tractor cost $1.25 per hour, bringing the cost to $2.63. To this is added the cost of fuel. Each of the two engines use 50 gallons of fuel oil for ten hours of operation, or a total of 100 gallons for a twin-motored tractor. This is a ten-gallon-an-hour consumption and at 7 cents per gallon, makes a total of 70 cents per hour for fuel. This brings the total to $3.33. Each Diesel engine has 6 gallons of oil in its crankcase or a total of 12 gallons. Figuring a cost of 87 cents per gallon, the lubricating oil totals $10.44, but this oil is changed every 50 hours of operation so that the cost is .2088 an hour. The oil in the transmission of the tractor is changed every 2000 hours of operation.

Since there are 220 gallons of oil required for each change and figuring at 87 cents per gallon, the cost amounts to .0957 per hour. The tractor and scraper are greased every 10 hours which increases the cost .05 per hour. The total cost up to this point is equal to $3.6845. The tires on the tractor list at $1780 each, making the total investment $3,560. The type of ground on which the equipment operates determines the life of the tires. On this particular job of running over clay soil and fairly level run-way, the tires would last 5000 hours. The cost per hour for tires would then be .752. To this must be added the hourly cost for the 4 smaller scraper tires. Each tire lists at $970, and figuring again on a 5000 hour life, the cost is .776 per hour. This brings the total now to $5.2125. The repairs include replacement of blades and cable to the scraper, field welding, parts and labor. The blade bolted to the scraper bottom is in three sections. The middle section lasts 600 hours and the outside sections last 800 hours. Figured on this basis, the cost runs 7 cents per hour. There is 932½ feet of cable used on the scraper and has to be replaced after 100 hours of operation, either part or the whole. Figuring on total replacement and the cost of 18 cents per foot, the cable cost per hour is $1.6785. Repairs and replacements of other parts vary considerably, depending on the type of ground moved, but in this case 20 cents per hour is rather conservative. Adding these items, the total cost is $7.1610 or $7.16. A summary of the cost per hour follows below:

Cost per Hour

Depreciation @ 3¢ per $1000	$1.38
Tournapull Operator @ $1.25 per hr.	1.25
Fuel Oil @ 7¢ per gal.	.70
Diesel lubrication @ 87¢ per gal.	.2088
Transmission lubrication @ 87¢ per gal.	.0957
Grease	.05
Tournapull Tires (2)	.752
Scraper Tires (4)	.776
Blade Replacements	.07
Cable Replacements @ 18¢ per foot	1.6785
Repairs	.20
	$7.1610

Note: This cost does not include interest, insurance, taxes, over-head, profit or supervision.

This grading as outlined above was done on a mile-and-a-half course with a 15-minute round trip. Since on each round trip 40 yards of earth was hauled and leveled, and 4 such trips an hour were made, then 160 yards was moved per hour. Figuring on 90 per cent operating efficiency per hour, the total pay yards is 144. The cost per yard amounts to .0497 or 5 cents.

By adding a bulldozer, which acts as a pusher on the rear of the scraper during loading, the pay yards per round trip increased from 40 yards to the capacity load of 59 yards, and the round trip time remained the same. To determine the new cost per yard, certain additions must be made to the analysis covering the Tournapull and scraper. The list price of the 'dozer is $8,700 and with a 3 cents per $1000 depreciation, .261 must be added.

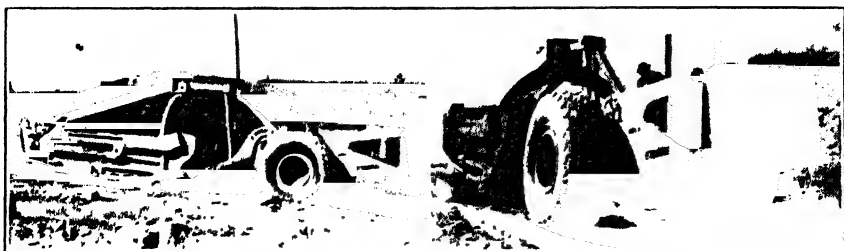



Fig. 11, (left). Tractor and 60-yard scraper in operation. Fig. 12, (right). Front operating view of unit.

The cost of the operator runs $1.25 per hour, also making the addition total $1.511 so far. The 'dozer uses 5 gallons of fuel oil per hour and at 7 cents per gallon totals 35 cents. The motor oil is changed after 50 hours of operation. This change requires 7 gallons and at 87 cents per gallon amounts to .12. Now, the oil in the 'dozer transmission (18 gallons) is changed every 300 hours. Figuring the same cost at 87 cents per gallon, the change amounts to .0522 per hour. The total additional cost now amounts to $2.0332. The 'dozer is greased every 10 hours and amounts to about 4 cents per hour. Repairs cost very little, but do run about 7 cents per hour. The total additional cost is then $2.1432, or $2.14; a summary is tabulated below:

Additional Cost

Tournapull and Scraper cost per hour	$7.161
'Dozer Depreciation	.261
'Dozer Operator	1.25
Fuel Oil	.35
Lubricating Oil	.1722
Grease	.04
Repairs	.07
	$9.3042

Again, using a 90 per cent operating efficiency per hour and four round trips, the total pay yards is 212.4. Then also, the cost per yard amounts to .0438 or .044. It is seen that a savings of $.0059 or ½ cent a yard was made possible by a small amount of additional investment.

By a similar analysis, a cost per yard was determined for a shovel, truck and 'dozer combination. The initial investment for a Diesel engined shovel runs about $37,000 and for each 5 yard dump truck about $2000. The round trip time required by each truck was 12 minutes. Approximately three

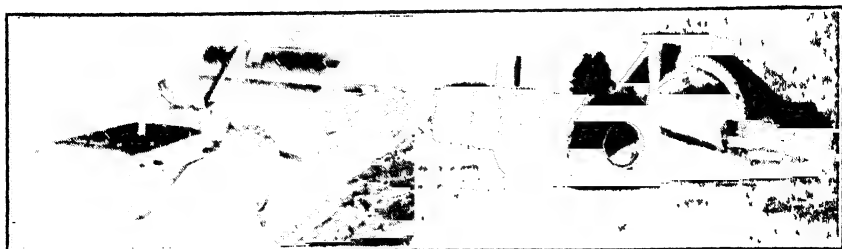



Fig. 13. (left). Another operating view. Fig. 14. (right). Side view of unit in action.

minutes were required for loading, thus limiting the number of trucks to four. The bulldozer as stated before cost $8,700. Therefore, the total investment is $53,700. With a similar 3 cents per $1000 depreciation, the total amounts to $1.611 per hour. As determined before, the total cost of the bulldozer per hour will be used as $2.1432. Figuring operator costs at $1.00 an hour for each truck operator and $1.25 for the shovel operator, the cost of operators amounts to $5.25 per hour. The fuel oil for the Diesel engine in the shovel should be the same for the other Diesels and thus amounts to 5 gallons at 7 cents per gallon, or a total of 35 cents per hour. About 30 gallons of gasoline was used by each truck in 10 hours, or 3 gallons per hour per truck. Figuring a cost of 16 cents per gallon, the total gas cost is $1.92.

Adding these costs, the total reaches $11.2742. As determined previously, a Diesel lubricating oil change costs .1044 per hour. Greasing and changing of oil in the trucks runs about 12 cents per hour. Repairs on the shovel and trucks will average very close to 20 cents per hour. Figuring that each tire costs $30 each and lasts 1200 hours, then, the tire cost per hour will be 40 cents. The total cost per hour then equals $12.0986, or $12.10 A summary of the cost follows:

Summary of Cost

Cost to operate bulldozer	$ 2.1432
Depreciation	1.611
Operators	5.25
Shovel fuel oil	.35
Gasoline for trucks	1.92
Shovel lubricating oil	.1044
Grease and oil changes in trucks	.12
Repairs	.20
Tires	40
	$12.0986

Since each truck carried 5 pay yards and each made 5 trips per hour, then the total number of yards was 100. Base on a 90 per cent operating efficiency as done on the other combinations, the pay yards total 90 per hour, and it is found that the cost is .1344 per yard or 13½ cents per yard.

The comparative figures as determined show quite a saving by the use of the tractor and scraper combination and still an additional ½ inch a yard by adding a bulldozer or pusher. The clay earth that was moved weighed about 2500 pounds per yard and the amount carried when heaped (59 yards) was more than a railroad gondola could carry.

The costs as determined in this paper are well in line for this particular

job. In other combinations of tractor, scrapers and pushers, and with different types of earth, the cost per yard varies from 3 cents to 10 cents.

The following is an article taken from the 1941 Annual Company Report:

"Because Tournapulls are quickly pusher loaded, haul at fast construction speeds and spread their own loads, they move yardage faster

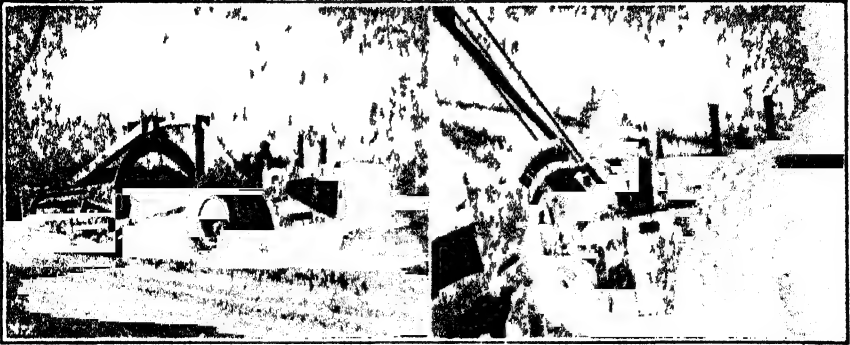



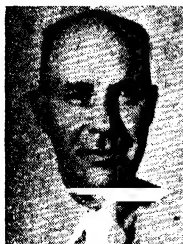
Fig. 15. (left). Unit fully loaded. Fig. 16. (right). Close-up of unit.

"As an example, take a 2,000-foot haul over good construction roads. Here, because of their high average speeds, 2 Super C Tournapulls plus a pusher (total weight 98,000 pounds) will dig, haul and spread as much earth as a 2½ yard shovel plus six 5-yard trucks and a spreading 'dozer (totaling approximately 245,000 pounds) That's a saving of 147,000 pounds of steel, vitally needed for Victory What's more, the Tournapull fleet requires 7 less men, cuts equipment investment almost in half and reduces cost per yard approximately 54 per cent"

In the conservation of man power, needed materials and time, a fleet of Tournapulls, Carry All scrapers and bulldozers is a definite trend

Chapter II—Gasoline Engine for Racing Automobile

By F. H. Andrews and Louis LaGreca,

Welding Superintendent, Paterson Boiler & Tank, Inc., Paterson, N. J. and Owner, LaGreca Machine Co., Paterson, N. J., respectively.

F. H. Andrews

Subject Matter: Construction of an all-welded steel gasoline engine for a racing automobile. The advantages claimed by the authors are saving in cost and weight compared to cast iron and elimination of leaky gaskets.

Louis LaGreca

This article deals with an all welded gasoline steel motor with over-head valves, of one-piece cylinder head and block construction, all of which were made from scrap steel and tubing.

It is a 4-cylinder 212-cubic-inch displacement motor, (See accompanying Figs. 1 to 5 inclusive), completely fabricated with steel. The only castings used were covers for timing gears and cams. These covers could have been fabricated from sheet aluminum or scrap steel but we had the castings.

The cylinders are made from 3⅞ inch inside diameter tubing 7¼ inches long with a solid piece of shaft 4 inch diameter by 1½ inches long welded to top of tubing, after having been machined to 7 inch radius outside and 5 inch radius inside for combustion chambers and also drilled and tapped for spark plugs.

The pistons were of cast aluminum.

Timing cams were welded to cold rolled steel and hard surfaced.

The manifolds were made from short pieces of 2 inch diameter tubing of ⅛ inch wall thickness.

The timing gears were flame cut and machined from steel.

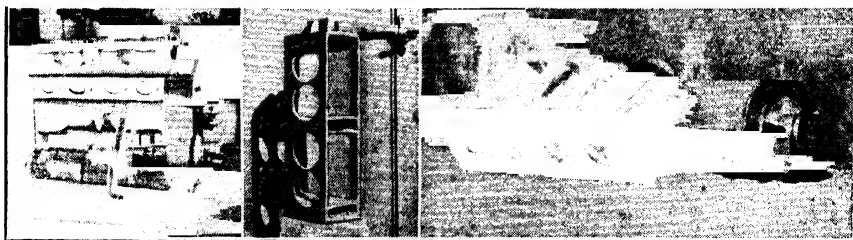



Fig. 1, (left). Unit assembled. Fig. 2, (center). Cylinder head. Fig. 3, (right). Cylinders and crankshaft in crankcase.

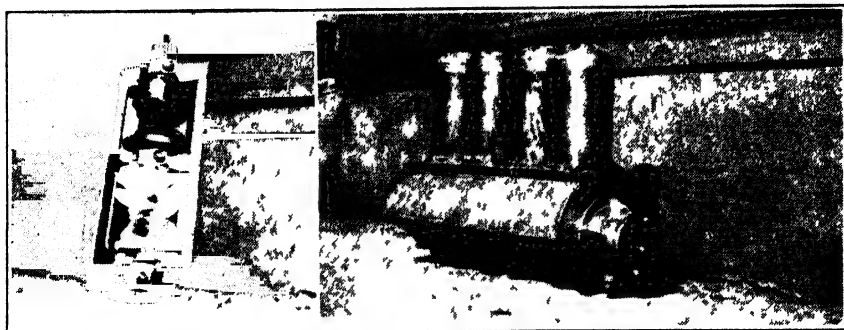



Fig. 4, (left). Crankshaft in crankcase. Fig. 5, (right). Cylinder mounted on crankcase.

The three main bearing blocks were made from 3 x $4\frac{1}{2}$-inch steel, flame cut and machined.

Crank case was made from $\frac{1}{2}$-inch plate, balance of crank case of $\frac{3}{16}$-inch plate.

Oil pan was made from 10-gauge plate.

Cylinder block covers and sides were made of 12-gauge, back covers of $\frac{3}{16}$-inch and front of $\frac{1}{2}$-inch plate.

Valve posts welded to cylinder head and sides.

Main bearing braces $\frac{3}{16}$-inch plate.

Nearly all of the above mentioned motor was made from scrap steel, with the exception of some of the tubing. All steel was bought at scrap price.

The actual machining time on the motor approximated 150 hours and the welding time about 15 hours. The weight of the motor equals 250 pounds.

This motor is to be used in a racing car.

The nearest comparable approximate price for a cast motor at retail price would be $2300.

Our costs below:

Item	Cost
Machining—150 hours @ $5.00 per hr.	$ 750.00
Welding — 15 hours @ $2.00 per hr.	30.00
Burning — 5 hours @ $2.00 per hr.	10.00
Parts, such as magnets, oil and water pump etc.	120.00
Spark plugs	3.00
Aluminum castings	30.00
Scrap Steel	5.00
Assembly	30.00
Pistons, connecting rods	22.00
	$1000.00

We believe, with some changes, this motor could be made for passenger cars.

Also a number of parts could be formed. Holes punched with dies in production would eliminate the largest part of the cost as parts were cut by a burning torch and bent by hand.

The original reason for making this motor from steel was to get away from gaskets which are always loosening up and losing oil, also to save weight in the front part of the car.

Chapter III—Universal Joint Drive Shafts

By W. W. SLAGHT

Chief Engineer, Cleveland Steel Products Corp., Cleveland, Ohio.

W. W. Slaght

Subject Matter: Method of mechanically welding a yoke to each end of a tubular drive shaft.

Introduction—Arc welding of the tubing to the yoke ends to make up the subassembly of a universal drive line is used quite universally by the universal joint manufacturers of this country and I believe the method for doing this operation is quite similar in all cases.

The following paper, while it will deal with the machine we use for arc welding and the procedure followed, is not primarily for that purpose. The real purpose is of relating a little improvement which has eliminated a trouble which had the earmarks of being a real headache.

To lead up to the problem we were faced with, a description of the machine is in order, followed by a line up of the procedure of operations and eventually our problem and what was done about it.

Description of Machine—The machine consists primarily of a bed similar to a lathe bed upon which is mounted two heads. One head, at one end, is fixed for position but, in turn, does the rotative driving. The other head is a traveling head and can be set to any position to care for the wide variation in lengths of shafts. These heads are equipped with centers for carrying the shafts to be welded.

The driving head is positively connected through a speed reduction to an electric driving means which can be adjusted to the proper desired revolutions per minute. It is also equipped with a lever for starting the mechanism and a cam shutoff mechanism so that the weld will make just one revolution plus a small extra for overlap.

Inasmuch as both ends of the tubing are to be welded to the ends at one time there are two coils of welding wire, one for each end. This wire is automatically fed when in operation by means of two individual mechanisms one at each end. Each of these mechanisms is controlled by two motors, one for feeding the wire faster and one for slowing the feed down. The control on these motors is by means of the fluctuation in current due to variation in arc. A short arc means the wire is feeding too fast and the motors will control the speed to slow it down and a wide arc means the wire is feeding too slow and the motors will control the speed to speed up the feed.

The electric power is supplied through the medium of two AC-DC converters running off of 220 volts, 60-cycle, 3-phase and converting to D. C. The D. C. volts and amperes are adjustable according to the discretion of the operator, to give the most suitable weld.

Procedure—The procedure as explained here will only involve the subassembly of a universal joint drive shaft. This subassembly is made up of a piece of tubing which is welded to its two ends or yokes. The two ends might be a yoke on one end and a spline shaft on the other end or yokes might be used on both ends. Let us refer to these ends as yokes. Our design covers both cases but the problem involved applies to either case.

The tubing used is first cut to length. The next operation bores the two ends of the tubing to a close tolerance so as to match the outside diameter of the end yoke hubs so as to give a press fit of from .005 to .011 when the yokes are pressed into the tube. At the same time the two ends of the tubing are bored out, they are also chamfered on the outside diameter with a 45° chamfer.

The yokes also have a chamfer at 45° to match up with the chamfer on the tubing. These two chamfers when brought together give a 90° V groove into which the arc welder must lay the weld.

The two yokes are now pressed into the tubing by means of a hydraulic press, provision being provided so as to give the proper length between boss centers of the yokes. The press fit mentioned above gives a sufficient tightness so that the entire subassembly will stay together during handling and straightening on centers which is the next operation.

This straightening operation is necessary so that a good alignment is obtained before welding. If this were not done, the straightening operation following the welding might impose considerable strain on the weld itself in order to put the entire subassembly in straight alignment.

This alignment is required due to the fact that these shafts are called upon to turn in excess of 4000 revolutions per minute and any misalignment causes undue vibration and whip.

The next operation is the welding. Both ends are welded simultaneously. Other operations follow but for our purpose we need not go any further.

The Problem—The problem that faced us was: "What could we do to overcome weld failure on our 2-inch diameter tubing shafts?"

A 2-inch diameter by 10-gauge seamless tubing was called upon to transmit 32,500 inch pounds' torque. The length of weld on a 2-inch tube is 6.28 inches which calculates 5200 pounds per inch of weld. The larger-diameter tubing did not bother us because, for instance, on a 2½-inch tube the length of weld would be 7.85 inches. This would resolve into 4140 pounds per inch of weld for the same torque required.

On the 2-inch tube, the failure was not an epidemic but only an occasional failure but it did indicate that we were near the ragged edge and that something had to be done about it.

By investigation and experimentation, we discovered that welds that were narrow and rose to a peak on the center line were invariably weaker than welds that were flatter with very little crown and were broad, covering not only the V-groove provided for the weld but spread at least 1/16-inch beyond the V-groove. (See sketches of before, Fig. 1, and after Fig. 2.)

Upon cutting open welds with the high peak, it was discovered that the core of the weld appeared crystalline and full of gas holes while upon cutting open the flat welds the condition of the core looked good all the way through.

Further experimentation was made with various welding electrodes but the results invariably showed that any wire that would peak was not so good while a wire that lay on flat was good.

The trouble could not be blamed on the electrode. A further experimentation on the voltage and current indicated that this also contributed to the success or failure of the weld.

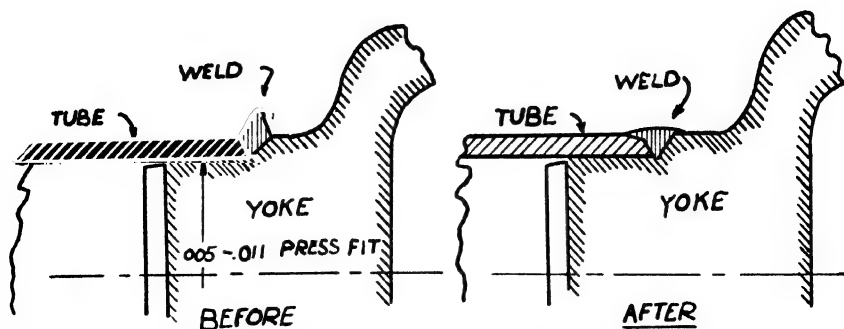



Fig. 1, (left). "Before," and Fig. 2, (right), "after" views of welds.

To obtain the flatter weld, it was necessary to increase the current requirement for welding. This was true regardless of the electrode used. The higher current driven through the welding electrode gave a hotter arc and we feel had considerable influence in flattening out the form of the weld. However, the character of the electrode had some influence on the type of core in the weld that was produced. Even though more current was consumed and, from this angle, the cost to the company was more to operate, the change was really to the advantage of the company.

The continual occasional weld failure kept us uneasy. We never knew when an epidemic might occur. The occasional failure began to make our customers uneasy and the feeling of mistrust in our welds was gradually growing. This uneasiness and mistrust was something that could not be measured in dollars and cents. It was a potential calamity which could occur. Something had to be done to rectify it. The change made in the form of the weld was that something.

Further than this the change-over was a distinct saving in dollars and cents because of the fact that if a remedy had not been worked out it would have been necessary to go to a larger tube diameter with its proportional increase in costs of tube and yokes. This increase would have amounted to 17 cents per shaft or on a year's production of this size, approximately $5000.

Besides this, the danger involving a weld failure cannot be overlooked. Traveling even at moderate speeds, a car or truck can be overturned by a ruptured drive shaft with subsequent possible loss of life and material damage.

Too much care cannot be exercised in the construction and manufacture of universal joint drive lines. An epidemic of failures might easily cause considerable loss of life as well as being costly. Welds must be correct and a job that is to be welded must be welded correctly.

Chapter IV—Arc Welding in Bus Construction

By D. F. Wagner,
Chief Engineer, Wentworth & Irwin, Inc., Portland, Oregon.

D. F. Wagner

Subject Matter: Welded construction of intercity busses. The chassis frame and side-supporting channels are welded and the aluminum body is riveted to the channels. The use of welding allowed the construction of this bus to be light in weight, (16,000 pounds), stiff, of pleasing design and easy to fabricate. The cost of riveted construction would be enough more to be impractical for the style desired.

The last 16 years has seen a remarkable advancement in bus body construction for our organization. Sixteen years ago the first body was completed for one of the local transit companies. Its frame construction was a mixture of riveted and welded members, riveting being used on gussets and other points of stress while welding was used for joining members and for finishing exterior rails for appearance. The following description gives an indication of how far we have advanced in the field of body building at the present time.

Modern bus body design is a mixture of appearance, serviceability, and long life. It can readily be said that all of the equipment now on the market meets all of these requirements. This means that the custom body builder must offer something more in his equipment as his sale price is usually higher than the regular market price because of the small quantity of units of one design produced.

Low net weight of a bus is a factor that the customer is interested in for the life of the unit as low net weight means more gas mileage, less tire wear, greater payload, ease of handling, and generally less wear on all chassis parts.

Fig. 1 shows a modern design capable of outperforming busses of a like capacity on these points. The 33-passenger bus shown is 35 feet long, originally designed for 37 passengers. The customer's requirements called for

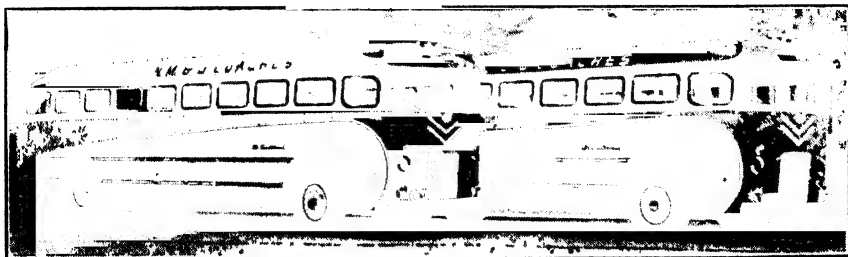



Fig. 1. Modern busses of arc welded construction.

Fig. 2. Bus frame.

greater baggage space which eliminated one row of seats at the rear. The level roads over which the bus would be used dictated the power requirements for a certain gross load The under-floor engine would provide a governed speed of 60 miles per hour with a gross load of 23,000 pounds set by the operator. A ready-for-the-road weight of 16,000 pounds was set by the operator after deducting 7,000 pounds for passengers, driver and baggage which was to be his maximum load

Our previous experience in construction of bodies of this size was in the heavier field for much more rugged service A unit of this size and capacity weighed 18,800 pounds less the air conditioning equipment The power requirement in this case was a larger engine which in turn meant a heavier

Fig. 3. Side of bus frame.

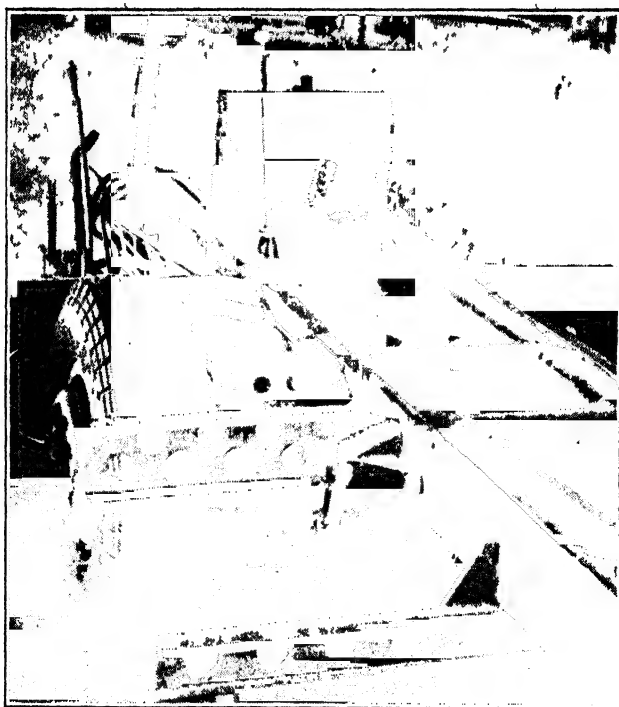



Fig. 4. Front end of chassis.

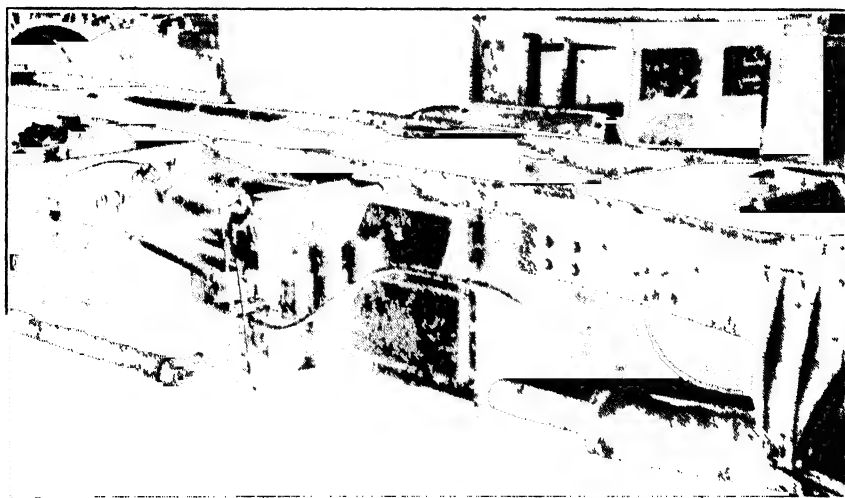



Fig. 5. Engine installation on chassis.

chassis and body and heavier tires because of the greater gross load. Our first analysis of the customer's requirements based on the heavier design indicated a bus of the same capacity plus air conditioning would certainly weigh more than 16,000 pounds net weight ready for the road. By neglecting past designs and thinking in terms of absolute minimum weight requirements, we finally set the weight of 16,000 pounds with air conditioning as being possible. To indicate how close this estimate was, the finished unit actually weighed 15,960 pounds.

The body consists of a high-tensile-strength steel frame with arc welded joints over which are riveted the aluminum panels. The body is connected to the chassis through outriggers welded to the chassis rails. Fig. 2 shows a front view of the frame paneled ready for mounting on the chassis. Fig. 3 gives more detail of the framing. The posts, longitudinal sill, belt rail, window header and roof rails can readily be seen. The body sills rest on beams while under construction previous to mounting on the chassis.

Figs. 4, 5, and 6 show the front of the chassis, the engine installation at the center of the chassis, and the rear of the chassis. The mounting outriggers are 16-gauge high-tensile-strength steel welded to the longitudinal rails with gussets. All replaceable castings and brackets are riveted to the frame while all other members are electric welded. The chassis is originally furnished as a separate unit by another manufacturer ready for the mounting of the body.

The longitudinal frame members previously mentioned are formed from high-tensile-strength steel cut from sheet stock. All of these members are 18 gauge in this design while normally 14 and 16-gauge mild steel members

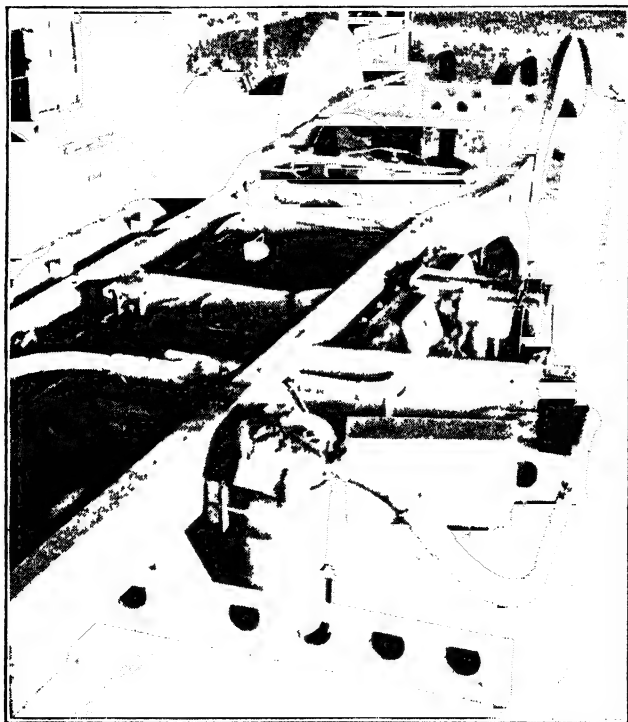



Fig. 6. Rear end of frame.

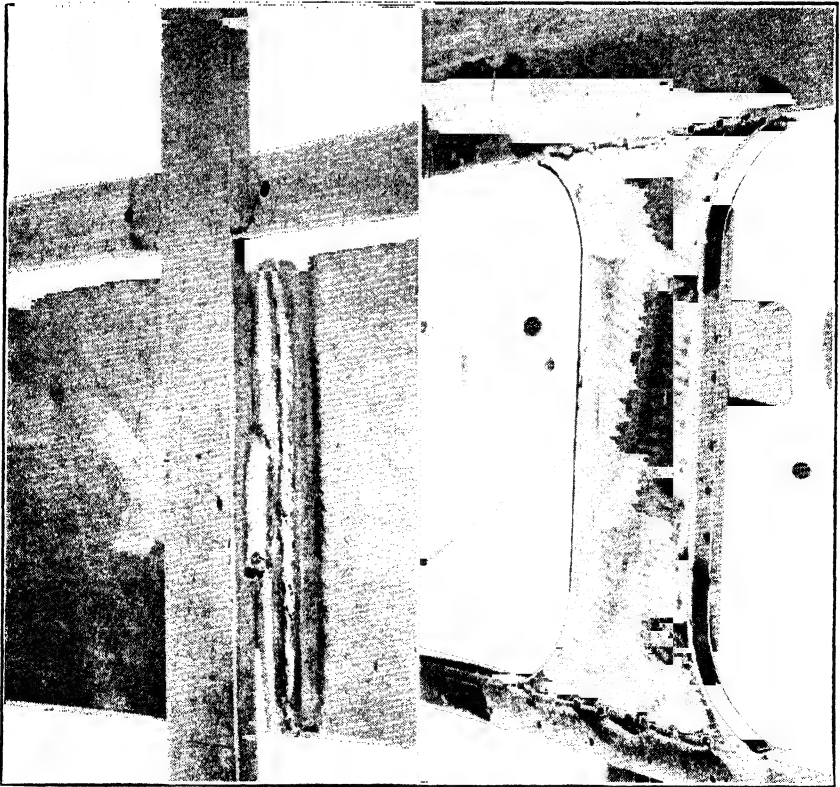



Fig. 7. (left). Sill and post joint. Fig. 8. (right). Pillar.

are used. The reduction in thickness is approximately 25 per cent as the high-tensile-strength steel has a tensile strength 25 per cent greater than that of mild steel.

The reduction in thickness reduces the weight but has the disadvantage of increasing the flexibility of the formed sections which cannot be tolerated in the usual type of construction. The body has the ability to transmit the load to the axles because it is a box member of rigid construction. An additional strain is set up in a unit of this design where the engine is under the floor between the two axles. In the particular chassis used, the frame rails were so light that they deflected an inch at the center with only the weight of the mechanical parts. This meant that the body must be designed to carry this additional load as the chassis is tied to the body.

The outriggers shown in Figs. 4 and 6 distribute the load to the body and are welded to the body posts and sills. The diagonal braces along the sides of the body between the sill and belt rail keep the body rigid without straining the side panels.

All frame members are electric welded to form a unit construction. The posts are mill-rolled members of "T" cross section 1¼ inches wide and deep with ⅛-inch thick webs. The posts are formed to include half of the carline. These members are joined with a splice at the center of the roof by welding to form a continuous arch from the skirt line of the one side to that of the

other side. The longitudinal members are notched to fit the posts before they are formed. These members are threaded on the posts to their proper stations where they are welded in place.

Fig. 7 illustrates the sill welded to the post. Stagger welds are used on wide sections to reduce warpage. The outside flanges flush with the outside of the post are welded on the inside to make a smooth joint. The long weld the width of the member close to the post is a butt weld used to join the 10-foot sill sections into a single rail.

Stampings and castings are normally used by many manufacturers for various parts such as panels between windows, corner fillets, corner posts, hinges and brackets. This is impossible for the custom builder as not many units of one design may be built.

Fig. 8 shows a steel panel of 20-gauge steel welded in place between the belt and window header. This panel is cut to shape and necessary sections to carry the sash and curtains are spot welded to it. The complete panel is tack welded in place to the two rails only. These joints are then soldered to make a smooth finish. This method has proved very satisfactory for fitting in various types of sash of special design.

The front corner posts shown assembled to the body in Fig. 2 can be seen

Fig. 9. Right front corner post.

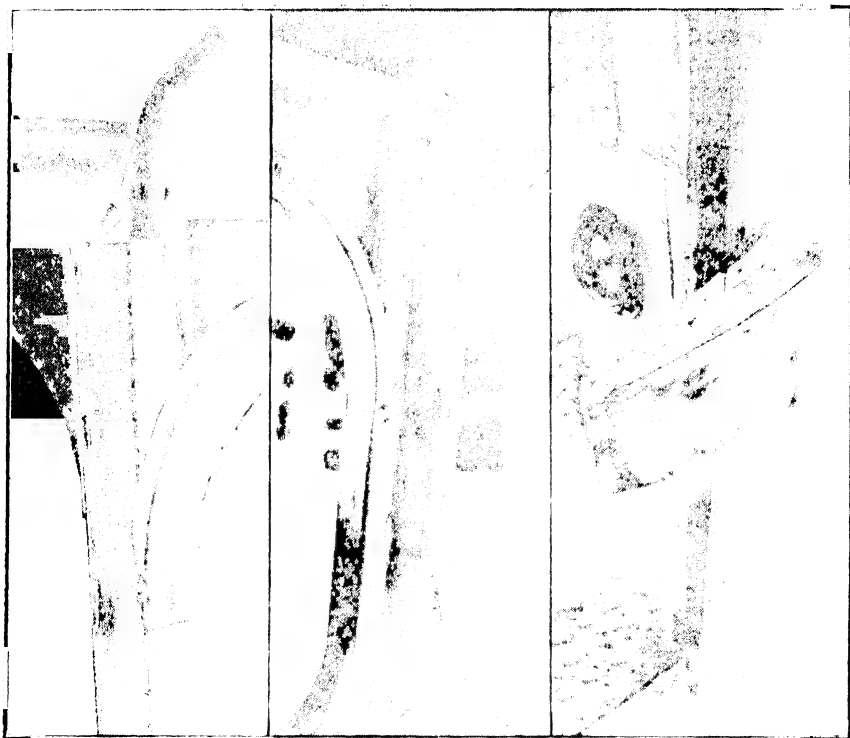



Fig. 10, (left). Back of right front corner post. Fig. 11, (center). Back of left front corner post. Fig. 12, (right). Lower door hinge.

in more detail in Figs. 9, 10, and 11. Fig. 9 shows the posts welded in place before the welds are ground smooth. The left corner post is assembled in the same manner except that the entrance door header is replaced by a window header. The inside of the right corner post is shown in Fig. 10 in which can be seen the conduit through which the electric wiring is drawn. This conduit is also welded in place after bending. Fig. 11 shows the left corner post with the gussets and headers welded in place. The posts and headers are fabricated from pressed shapes spot welded and arc welded together to form unit members.

The contour of the entrance door and the slope of the corner post required a different type of hinging than the usual piano hinge. A pair of fabricated hinges were designed to hold the door vertical when it was open. Fig. 12 illustrates the design of the lower hinge in place on the corner post. The hinge point is several inches ahead of the back of the door post at this point. The outside cap is bolted to the door and it also covers the fabricated stationary part of the hinge. The hinge is fabricated of $\frac{1}{8}$-inch steel plate formed to shape and electric welded.

Many special brackets are required in the construction of the body of this type to properly support various types of equipment. The air conditioning engine, compressor, and condenser are mounted on the right side of the body opposite the engine and directly under the raised floor between the aisle and the side wall. Light-weight brackets are welded in place to support this equip-

ment between the chassis frame and body sill. Many brackets are designed as the body construction progresses as it is impossible for the manufacturer to completely design all items required for the body assembly when there are a limited number of identical bodies to be built.

Electric welding is a very handy tool for setting up the body frame as cross braces are normally used to keep the frame square during assembly. Angles are usually used for this purpose. A light weld holds these ties in place and allows them to be broken loose when they are no longer needed This item alone is quite important as it is impossible at times to clamp ties in place.

Many times the manufacturer of various types of equipment is not in a position to estimate the savings that might be anticipated from the use of his equipment as it is impossible to determine the exact use to which the equipment will be put. Experience indicates that the type of bus described should have exceptional performance over a period of time. This is brought out by comparative performance with equipment of the same load-carrying capacity Maintaining schedules is very important and the operator's experience shows that this bus is capable of operating at greater speed against adverse conditions that normally slow up other types of equipment showing that the weight per horsepower is very satisfactory for this operation.

The welding time is a relatively small percentage of the total construction time required for the fabrication and assembly of a bus of this type. The

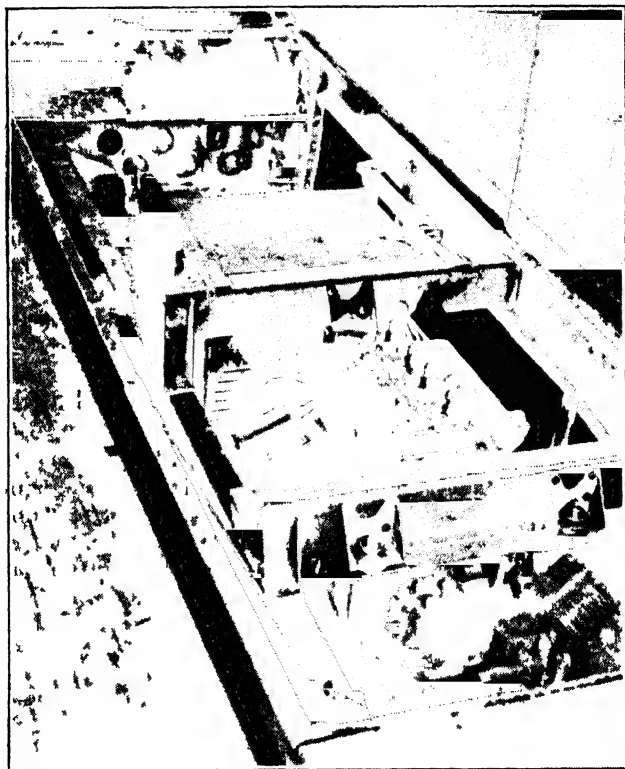



Fig. 13. Air conditioned power unit.

hours of labor for the construction will vary with different manufacturers depending upon the experience of the men and the type of tools and machines used.

The total number of labor hours was 2408 with the following break-down: welding time 79 hours or 3.2 per cent; fabrication and forming of pressed and sheared parts 132 hours or 5.5 per cent; forming of posts, angle iron frame rails and corner angles 21 hours or 0.9 per cent; fabrication of seats 428 hours or 17.7 per cent; painting 165 hours or 6.8 per cent; and remainder of all other work 1583 hours or 65.9 per cent.

Most of the welding time is built up a few minutes at a time as most of the welds are very short in length. This makes it impossible to arrive at a cost of various types of welds that go into this type of framework.

The actual labor cost not including overhead can be figured at $1 per hour as an average. This sets the labor cost of welding at $79 which is only 3.2 per cent of the total labor cost. The increase in labor cost would mount rapidly by the use of riveted joints. First of all, the design of the body would be changed for riveted joints which would put a prohibitive design cost against one or two bodies. Additional time would be required to fabricate the joint gussets. More labor would be required to drill rivet holes and then two men would be required to drive the rivets. An estimate of 160 hours' additional time for this work would increase the manufacturer's cost $160 for a less satisfactory job. The completed bus would not have the same sales appeal because of appearance and construction. Many of the rounded corners and joints would be eliminated as there is no other satisfactory means of making a proper ınection.

Chapter V—Welding of Armor Plate for Tank Production

BY EDWARD G. BIEDERMAN,

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Subject Matter: Riveted tanks will not stand shell fire or shock. Arc welded armor plate can be made quicker, more satisfactorily and at lower cost. One electrode, referred to in the paper as "Electrode No. 2", was first used without success, later another rod, referred to in the paper as "Electrode No. 1", was found satisfactory to withstand 75 millimeter shell fire. Many different angles and techniques used and illustrated. Fixtures were made so all welds are downhand. Much difficulty from internal stress. Much research was done and 45° bevels on both sides of flat plates seem to be best.

Welding of Armour Plate for Tank Production

The arc welding process has opened an entirely new field of manufacturing, that of welded tanks. The methods that have been developed can be used on every type of welded fabrication, in many cases to a big advantage on present work, and to a tremendous advantage on future fabricating work.

Welded tanks are a necessity for saving human life. The riveted tank previously made would not stand the shell fire or shock, and this reason was enough to bring a new and better method to the front. This country must have thousands not hundreds of tanks. The arc welding process was a logical choice.

Through extensive developments, manufacturers are holding tolerances that have previously been asked only from the machine tool industry and are learning every day that if more effort is put behind welding fabrication, the demand for machine tools is reduced tremendously. Riveting requires many times the amount of machinery. Most important is that through welding we will be able to manufacture tanks in large volumes, not be dependent on large volumes of machine tools and not be dependent on inadequate foundry capacities.

Welding eliminates hundreds of pounds of butt straps. This means less weight per horsepower and increase in performance.

Welding process saves a large amount of machine tools due to flame cut edges and drilling of holes.

Trials and Procedure Before Manufacturing Tanks

1. We started welding operations with different ferritic welding rods. This ended in complete failure due to the high alloy and high hardenability of the armor plate, also, because we did not preheat and postheat or anneal. Failure was due to excess cracking at fusion zone and welded metal. Under shock firing above plates fell apart with first shot at about —— foot seconds.

Above tests did not go into detail of warpage or trying to hold limits for manufacturing due to the fact of failure of welds.

If armor plate changes to low enough alloys and has low hardenability,

ferritic rods should do the work, but at this date it does not exist for manufacturing facilities. It, also, will not pass ballistics and shock test as set up by the U. S. Army Ordnance.

2. Tests were made with an austenitic rod. This rod was more successful and sound welds were made and passed Aberdeen proving ground.

Using the above rods caused a series of troubles as root bead, cracking and excessive grinding and chipping.

At this time alloys were hard to get and it looked as if a suitable rod would not be available for tank manufacture.
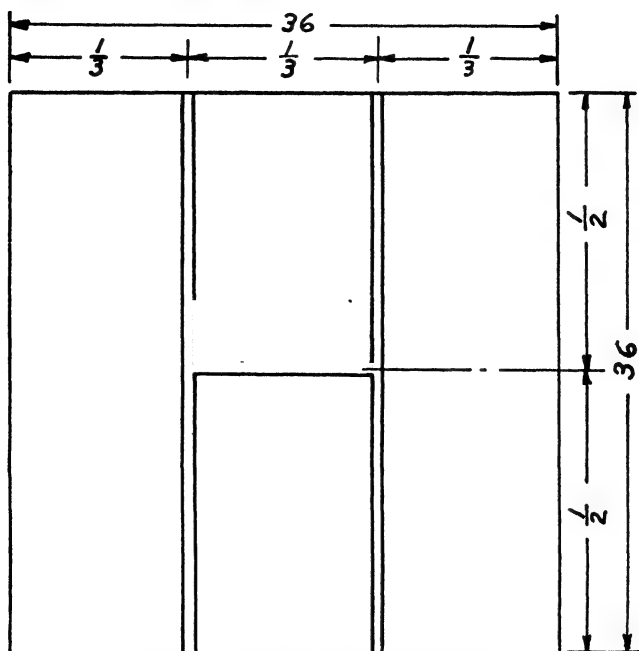
Fig. 1. Shock test plate weldment.

Welding electrode manufacturers started to develop a lower alloy rod which, for purposes of this discussion, will be known as "Electrode No. 1". Extensive development was necessary for welding high alloy and high hardenability armor plate. Better results were obtained as shown in the following tests:

Less cracking in fusion zone.
Less cracking in weld metal.
It had better ballistics for weld deposit.

But the deciding test is the shock test developed by Aberdeen proving ground. This consists of an (H) plate weldment 36 x 36 inch wedged into a standard and fired at by a 75 millimeter gun at 100 yards, (See Fig. 1). The shell did not penetrate the weldment but was used to give the weld a very severe shock. It was found out that the electrode which shall be referred to here as "Electrode No. 2" would not stand the same shock as "Electrode No. 1" would. The outcome was that besides saving alloys a better rod was found for manufacturing tanks. From here on "Electrode No. 1" was used exclusively except for tests with "Electrode No. 2" and an actual savings of
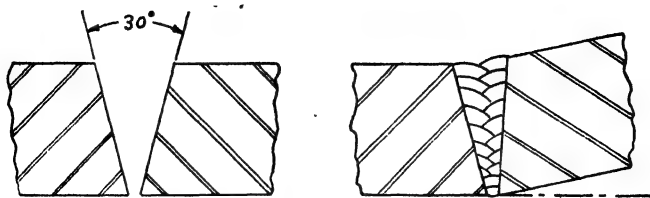
Fig. 2, (left). Unsuccessful type of plate preparation for tank manufacture. Fig. 3, (right). Single-V type weld which was discontinued except for test purposes.

approximately 33 per cent was made in cost of welding electrode, and chrome nickel alloys.

Welding Technique

1. Present every day welding preparations were found lacking in manufacturing tanks. This was due to tolerances that had to be held in manufacturing and, also, the shock test demanded by Government and necessary in use.

2. There are very few fabrications in low carbon steel or otherwise that must stand inspection shock test of a 75 millimeter shell or be held to such close tolerances in building. This meant a new development of plate edge preparation to keep warping to a minimum.

All plate edge preparation is with the flame cutting method. This means flame cutting must be held at much closer tolerances. No edge for welding should be done otherwise because of the savings possible. If edges are machined it means tying up machine tools, labor and takes a lot more plant space. It is almost impossible to estimate this savings in dollars and cents because of the release of machine tools for other necessary work. It is tremendous. It has now been proven that a flame cut edge can be held within limits for tank building.

3. The single V-15°, 20°, 30° or 40° has been in use as a standard plate edge preparation for normal welding fabrication. This preparation has not been successful for welded tank manufacturing, (See Fig. 2).

4. This weldment was very unsatisfactory. Despite use of extensive fixtures made to hold welded parts, warpage from shrinkage could not be controlled. After trying 20°, 30° and 45° single (V) was discontinued except for test purposes, (See Fig. 3).
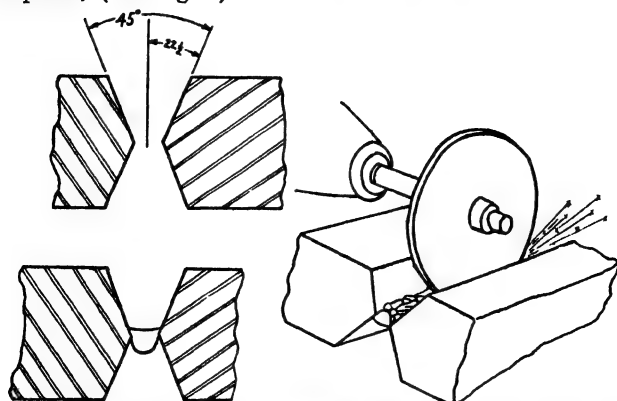
Fig. 4, (top left). Double-V weld. Fig. 5, (bottom left). Root bead. Fig. 6, (bottom right). Grinding root bead.

Reason for above failures of (V) edge preparation. Tanks must be fabricated by welding and hold tolerances of 1/64-inch at places where parts bolt to tank such as front end drive, suspension wheel, idler bracket, turret ring and a lot of other assemblies.

Close dimensions like these have never been held before on a fabricated part. They were always welded and then machined. If it was possible to machine different areas of the tank the machines are not available. That is why we must weld and hold tolerances just the same as machine parts. The double (V) was then adopted, (See Fig. 4). It must be understood that a double (V) takes double the edge preparation that a single (V) takes, but it was found to be the answer for weld strength and the only possible way to hold tolerances through out tank manufacturing on a production basis minus machine tools. The double (V) has been used before but never had to be held for tolerances such as tank production. Certain bead technique had to
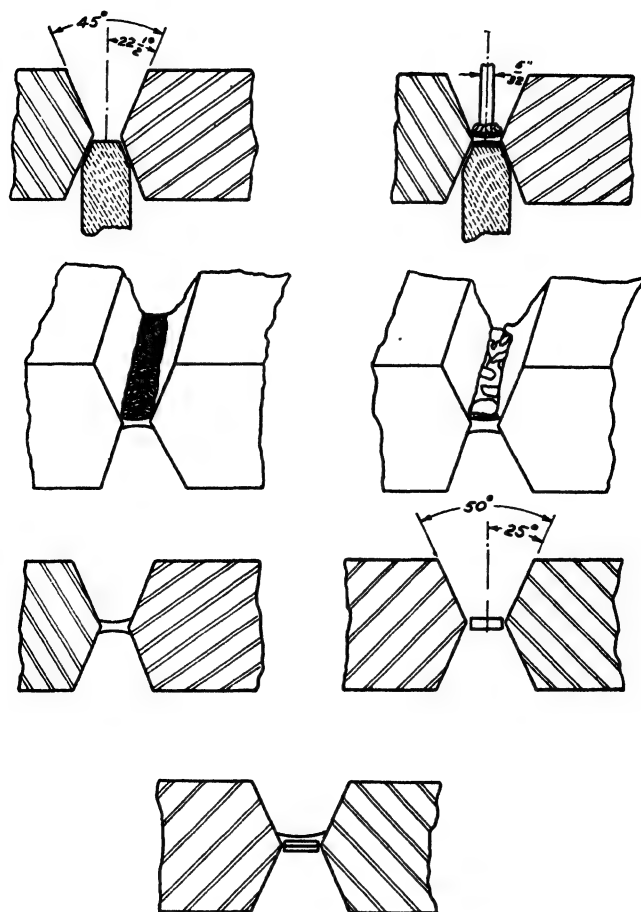
Fig. 7, (top left). Copper bar inserted. Fig. 8, (top right). Weld in down hand position. Fig. 9, (second from top, left). Top side. Fig. 10, (second from top, right). Side of copper back-up. Fig. 11, (third from top, left). Ideal condition for receiving additional beads. Fig. 12, (third from top, right). Root bead test. Fig. 13, (bottom). Incomplete penetration.

be used to control warpage, and shrinkage as illustrated after root bead is welded part shrinks and that is when plates warp, (See Fig. 5). Welded part must then be turned over and weld from opposite side. This procedure must be followed to equalize stresses. When welded technique is used to equalize stresses it is then possible to hold dimensions without stress relieving and machining.

Development of the root bead was very important as the root of the weld is the foundation of a good weld.

First root beads were welded with a 45° included angle and an opening. This is a very impracticable procedure as the weld metal runs through and the back side must be chiseled out or ground. Chiseling is very bad on stainless steel as the metal is austenitic and work hardens and the chisel just pounds against a solid formation. This meant grinding all root beads as Fig. 6. This procedure meant 30 minutes of welding and 180 minutes of grinding. We then discontinued the procedure because it did not lend itself to manufacture tanks.

The next experiment of welding a root bead was with a copper backing. Two plates were set up with a 45° included angle and an opening. A copper bar was then inserted in the under (V) and had about $1/32$ inch clearance on each side, (See Fig. 7). It was then welded in down hand position from the top side, (See Fig. 8).
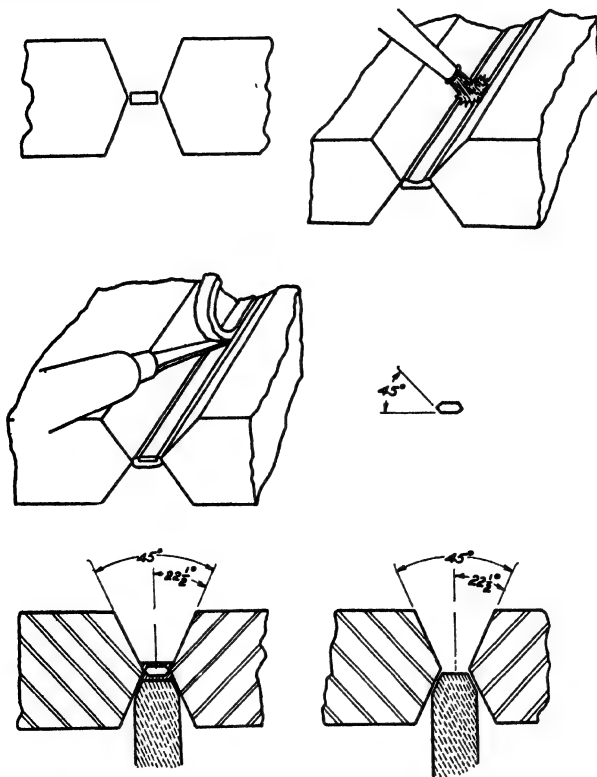
Fig. 14, (top left). Strips welded from one side. Fig. 15, (second from top, left). Chipping weld with chisel. Fig. 16, (top right). Gouging tip on acetylene torch. Fig. 17, (second from top, right). Chipped to diamond shape. Fig. 18, (bottom left). Complete penetration. Fig. 19, (bottom right). Double 25° included angle with opening.

After root bead was welded, copper was taken out and the root bead was inspected from both sides. Fig. 9 was top side and Fig. 10 was side where copper received weld metal. If you look closely at Figs. 9 and 10 you will notice that no grinding or chipping is necessary, also where copper received weld metal there was a concave, which is an ideal condition for receiving other weld beads, (See Fig. 11).

After this test of welding a root bead we felt as if this would lend itself to production, the reasons are as follows:

The weld was made and there were not any voids, which make for an unsound weld, and also, weld was in condition for receiving other bead by just removing the slag.
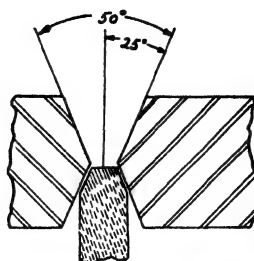
Fig. 20. Test of 50° included angle with copper back-up.

The next test of a root bead was made with a mild steel strip between a double 25° angle with an opening, (See Fig. 12). This method eliminated weld metal coming through but left voids of openings between strip and weldment. This naturally was not good enough because it did not have complete penetration, (See Fig. 13).

It was then decided to weld strip from one side, (See Fig. 14), and chip it out so a sound weld could be made, (See Fig. 15), but this procedure was eliminated because it was almost impossible to chip strip out of corners or around bulkheads in the tank. It was then thought to use a gouging tip on an acetylene torch gouging the strip out was better than chipping but this was difficult to maneuver around corners of the tank and it left a certain amount of carbon deposit that was a detriment to the weld. This was eliminated as not being good for production and quality weld. Fig. 16 shows flame-gouged strip.

We then developed a stainless steel strip diamond shaped or oval that would not have to be chipped or flame gouged, (See Fig. 17). This was successful as it would lend itself to production and would also be good weld as complete penetration was possible, (See Fig. 18). With the copper back up and the diamond or oval strip we felt that here were two methods of producing a good weld with complete penetration for manufacturing tanks.

Now it was time to develop the proper bevels for welding. You must keep in mind always that the heavier the plate the more welding rod is used.

It was decided that a double 25° included angle with an opening would be tried as it would not use excess weld metal, (See Fig. 19). A copper back up was used on these plates. After a few of these test (H) plates were fired it did not look as if our welds were good enough. It was then decided to try an (H) plate welded with "Electrode No. 2" but, this plate failed quicker than the "Electrode No. 1" did under shock.

Most all the breakage was what is commonly known as a fusion zone
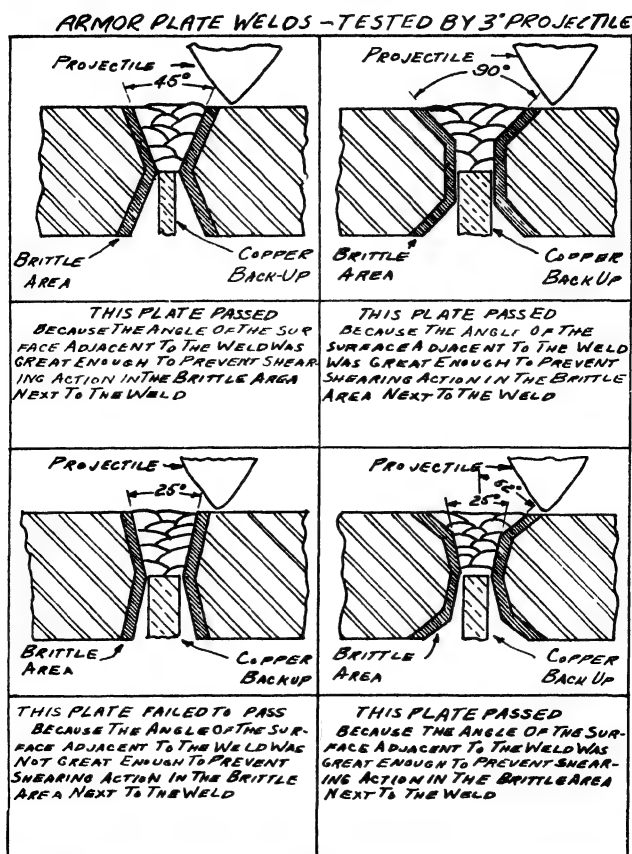
Fig. 21, (bottom left). First in series of welded test plates. Fig. 22, (top left). Second test plate. Fig. 23, (top right). Third test plate. Fig. 24, (bottom right). Fourth test plate.

break. At this time we did not really know what a fusion zone break concerned.

We then decided to make other tests using "Electrode No. 1" and with a 50° included angle with an opening, (See Fig. 20), with copper back up. After making a series of (H) welded plates this way we found that the fusion zone cracks were almost entirely eliminated. The welding, understand, was done with the same welder and using a weave technique. That told us that the bevel used was very important. Keeping in mind that we were welding a high-alloy armor plate with a high hardenability.

We then decided to make a series of (H) welded test plates with different plate edge preparation. We felt that if the test plates failed so would the tanks fail.

The first plate was prepared with 25° included bevels as shown in Fig. 21. The second plate was prepared with a 45° included bevel as shown in Fig. 22. The third plate was prepared with a top and bottom bevel of 90° included angle as in Fig. 23. The fourth plate was prepared with a top and bottom bevel of 104° included angle as in Fig. 24. All (H) plate weldments were welded with the same rod the same welder and all had a copper backing bar such as the figures show.

After these plates were shock-fired, we knew that the bevel played a very important part in welding and manufacturing tanks. It showed that a lot of fusion zone cracks were because the bevel was too straight and the hard zone right at the fusion point would let go because it was almost in line with the line of shock. By keeping the hard zone from almost a direct line of fire we achieved very good results.

These tests proved to us that no bevel should be less than 45° and that if at all possible we should avoid bevels on one side and straight on the other side. Welds will generally break through on straight side because hard zone is in line with shock, (See Fig. 25). All tests were made with same welder and same manufacturers' "Electrode No. 1". After these tests we knew which plate edge preparation was best.
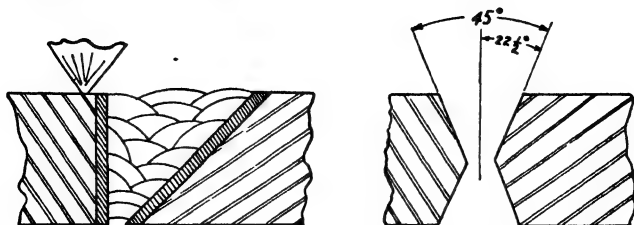
Fig. 25, (left). Hardened zone in line with shock. Fig. 26, (right). 45° included bevel with opening.

The next step was to prove what armor plate was the best for welding. Four types were agreed on. After receiving 16 plates, four from each source, we prepared them all the same 45° included bevel with a root opening, (See Fig. 26). All 16 plates were welded with the same welder, same "Electrode No. 1" and the same technique.

After this test we were able to determine the most weldable armor plate, and it also helps the armor plate manufacturer to make better plates for welding.

We then decided it was time to find out which rod was the best for welding armor plate.

Again we took 16 plates but all from one source and decided to weld them as follows: Rod manufacture "A", 4 plates, Rod "B" 4 plates, Rod "C" 4 plates, Rod "D" 4 plates. After these tests were completed we then knew which "Electrode No. 1" rod was the best. Also when we had this evidence the rod manufacturers changed their coatings and all are good rods now.

Considering the cost of such welding, estimated savings from less rejects can be estimated only, but more than justify any cost of extensive experiments. A few more miles from each tank in actual use may mean actual winning a crucial battle.

After having the experience and the data from previous tests, we started building fixtures and manufacturing tanks. As previously mentioned the one big problem was warpage and trying to control same.

All the fixtures were designed so that all welds could be made down hand. Also, that fixtures would rotate and always make it possible to weld from both sides. This is necessary on account of equalizing stresses. Fig. 27 shows a typical fixture.

The first tank was welded on a surface plate and it was difficult to equalize welding from both sides. We immediately found that by neglecting equalizing technique our dimensions were very hard to control. Also, we had welds that

sheared apart due to stresses from welding more on one side than the other. From the above trouble it was found that we must equalize the shrinkage stresses on all of our welds. It was then found that our dimensions were easy to hold and we did not encounter any more weld cracking or shearing from warpage or stress from welding. All fixtures are made so that each part is a sub-assembly, then checked O.K., so it can be set up in the next fixture easily and quickly.

Welding technique to equalize stresses is the biggest factor of welding tanks after quality is determined. It means you can make sub-assemblies up before hand and know they will fit into the following fixture and assembly quickly. Also, when the tank is completely welded, it will stay in good condition longer. If you do not equalize the welding, undue strain at some point that is already strained to its maximum will fail. The weld break or twist to favor the stress. If the sub-assembly methods are used it will be possible to build many more tanks due to the fact parts can be welded any place and final assembly only involve a few fixtures instead of having all final assembly fixtures. This is a very vital necessity in time saving, fixtures, floor space and machine tools.
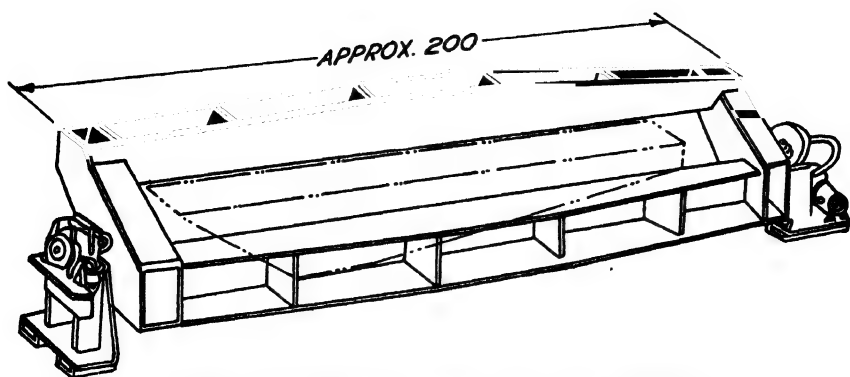
Fig. 27. Typical fixture to permit down hand welding.

Another Vital Saving Is Made in Labor—Labor savings can be accomplished as the smaller fixtures can be worked from the floor. The men must climb into the larger fixtures, so, in using more small fixtures and less large fixtures, your welders will be able to weld more inches per hour. This is important as welders will be scarce and estimated saving in this layout can be tremendous.

The main objective is to produce tanks and armored vehicles in the least time possible and have equipment superior to any that will be met in combat. To accomplish this, the foregoing was worked out and recounted in this article for one purpose—TO WIN—and the following reasons to accomplish this:

To produce quicker.

To produce faster after starting production.

To produce for less money.

The real savings can only be determined on the value placed on our winning the final decision.

Chapter VI—Small Truck for Loading Freight Cars

By Elverton W. Weaver,
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Elverton W. Weaver

Subject Matter: The truck was made 35 inches wide in order to clear 3-foot doors and with welded lifting arms provided on the front end. The capacity of the arms is 3000 pounds and they can store merchandise to a height of 15 feet. The truck is only 40 inches long and has a radius of 70 inches. The cost of welded construction is 36 per cent less than riveted construction and one man can unload 150 tons of wood pulp per day from a freight car.

In a recent issue of the United States News there appears an advertisement by the Santa Fe Railroad Company urging as a patriotic duty the conservation of railroad car operating time. Quoting from this ad, "Every 1 per cent increase in freight car utilization gains 19,552 cars for war transportation." Further along appears this statement, "Last year, with your help America's Railways increased the productivity of their existing freight cars by 23.7 per cent over 1940 . . . through increased efficiency on the part of railroads, shippers and receivers of freight."

A considerable factor in these savings has been the use of mechanical load-handling equipment. The purpose of this paper is to discuss the main design problem in the development of a machine for this purpose and its clean-cut solution, made possible by the electric arc welding process.

This machine, shown in Fig. 1, was brought out late in 1940 to meet the need for a smaller and more flexible unit. By its use, the loading and unloading of a car becomes a matter of minutes instead of hours. It has the ability to pick up and transport loads with speed and dispatch, threading its way along narrow aisleways. It will raise and deposit its load at any desired height up to 11 feet. In fact, it is a speedy, traveling elevator.

Figs. 2 and 3 are photographs of the machine in action. That compactness is a prime essential in the design of a machine for this work is shown by Fig. 4, a diagram of its operation within the car.

Machines of this general type are not new. In fact, the railroads pioneered in seeking an answer to quicker loading and unloading of cars. Quite an industry was built up to help them in the solution of this problem. The early trucks were all electric-storage-battery powered. This source of power in itself imposed definite limitations. The low platform lift did not permit of tiering loads and the construction was crude and bulky.

In 1933, the company entered the lift truck field with the machine shown in Fig. 5. This was a fundamentally new combination of elements, each of which had been proven in other applications. These were: a, Gaso-
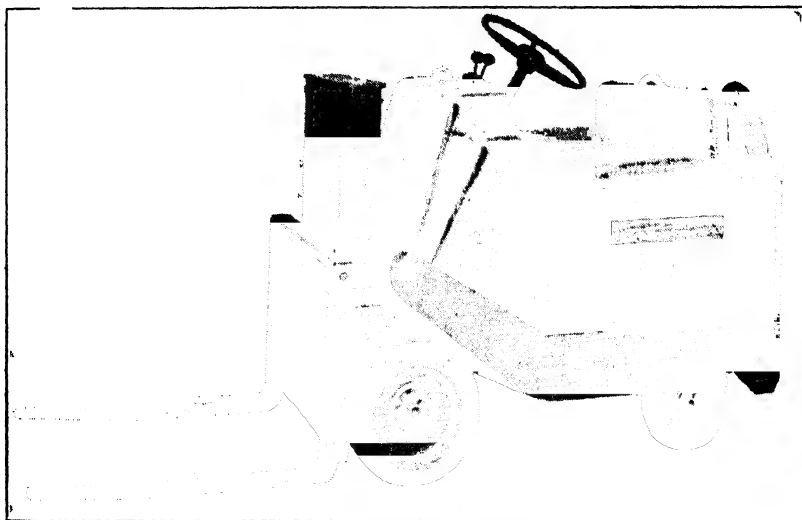
Fig. 1. The subject of study.

line engine power. b, Driving wheels at the front end, steering at the rear. c, Hydraulic means for lift and control of load d, Central seating for the driver, giving him full vision, comfort and safety, and e, An electric welded frame structure.

That this is now practically standard construction for industrial trucks of this type speaks well for the vision of the head of the company and designer of the truck. This machine, as originally designed, was for 4000-pound load capacity at 24 inch load center It was 40 inches wide, with 56-inch wheel base, and had an overall length, less load, of 93 inches Its overall height was 84 inches, and it could lift its load 52 inches. It had an outside turning radius of 96 inches

The marked savings effected in material handling where this machine was put into use brought a constantly increasing business to the company all through the depression years Electric arc welding made possible the practice of "tailor making" each machine to fit the needs of the customer Masts
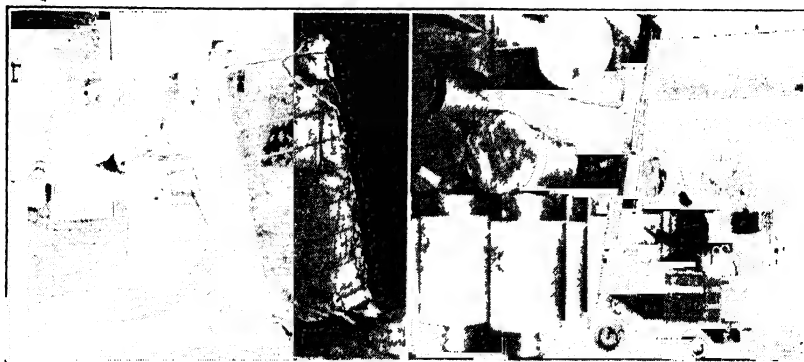
Fig. 2. (left). Loading truck in action. Fig. 3. (right). Handling news print.
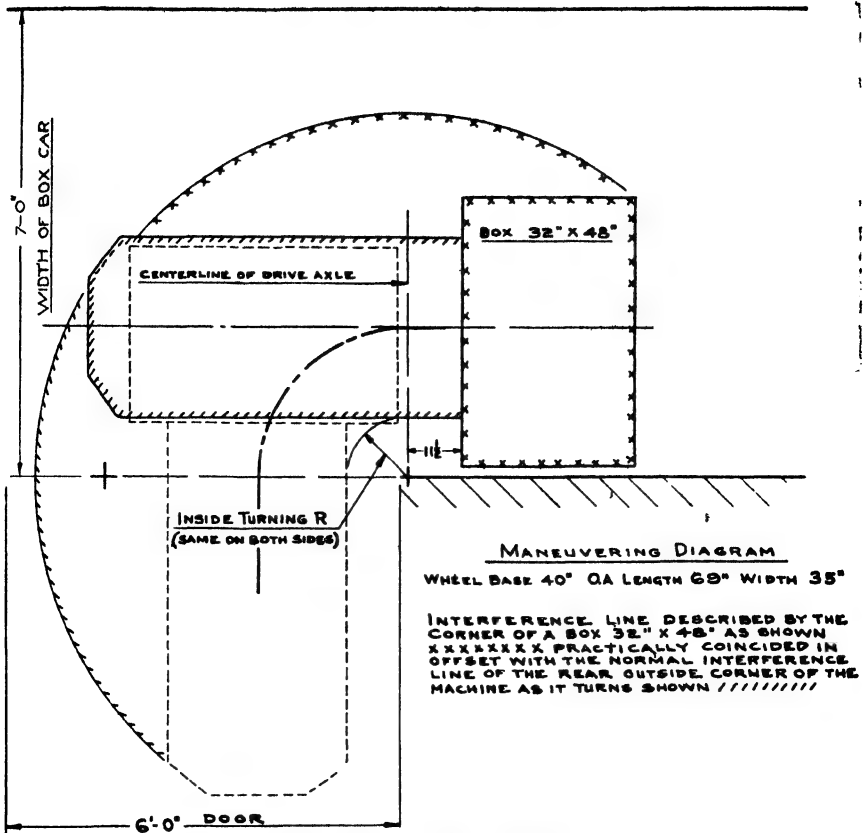
Fig. 4. Maneuvering diagram.

were made of special heights to give any desired lift Wheel base and other factors were modified so that constantly increasing capacity was obtained Today, the machine is being built with wheel base up to 72 inches and capacity rating up to 10,000 pounds at 25-inch load center See Fig. 6 for present example of this model

Early in 1940, the writer was given the task of the design of a smaller capacity machine In addition to the five fundamentals ("a" to "e" outlined above) tentative general specifications were laid down as follows: f, Maximum capacity—three thousand pounds at fifteen inch load center; g, Most compact design possible and with minimum turning radius, h, Full accessibility to every service part; and i, Standardized construction to permit of mass production technique. The final specifications worked out to be· width, 35-inch, wheel base, 40-inch, overall length without load, 70-inch, outside turning radius, 68-inch. Provision was made for mast heights to give lifts of 7, 9 and 11 feet The most popular height proved to be the one that will nicely pass through a seven-foot door and will lift to a height of nine feet.

Not much need be said in regard to the general design of the truck, except that throughout the design electric arc welding has consistently been used—mast, carriage, tanks, cowl, etc all being of welded construction. The
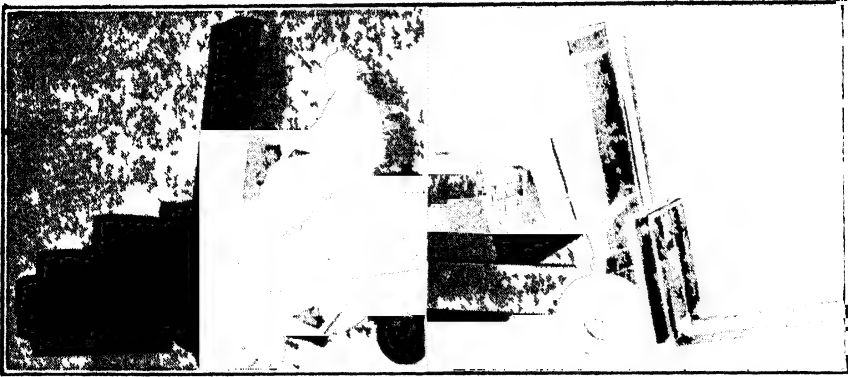
Fig. 5. (left). 1933 model. Fig. 6. (right). Widely used type loading truck.

unusual frame, made possible only by the arc welding process, is the particular reason for this paper.

Construction of the older model at the drive axle is shown by the separate photographs, Fig. 7 and Fig. 8. The wide flanges close to the wheels will be noted on Fig 7 of the axle, and the mating flanges on the frame are clearly shown on the left hand side of Fig. 8. The tubular bar just above at this point on the frame is for the mast hinge

In the design of the smaller model, it was desired to lower the driver's seat, thus giving easier access to the driver's position This necessitated lowering the engine so that the crankshaft centerline was on a level with the top of the frame and the flywheel and its housing must lay between the two side members.

The important functions of the frame are as follows. First, it must carry the mast with its load Second, it serves as the platform on which all the machinery, power plant, etc. is mounted It also provides space for the operator. Third, attached to the frame on the under side are the springs, axles, wheels and other supporting elements. Fourth, the frame should
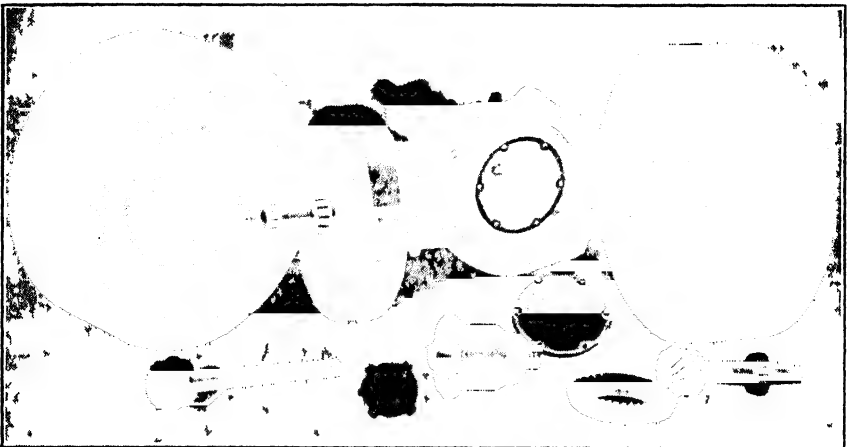
Fig. 7. Drive axle.
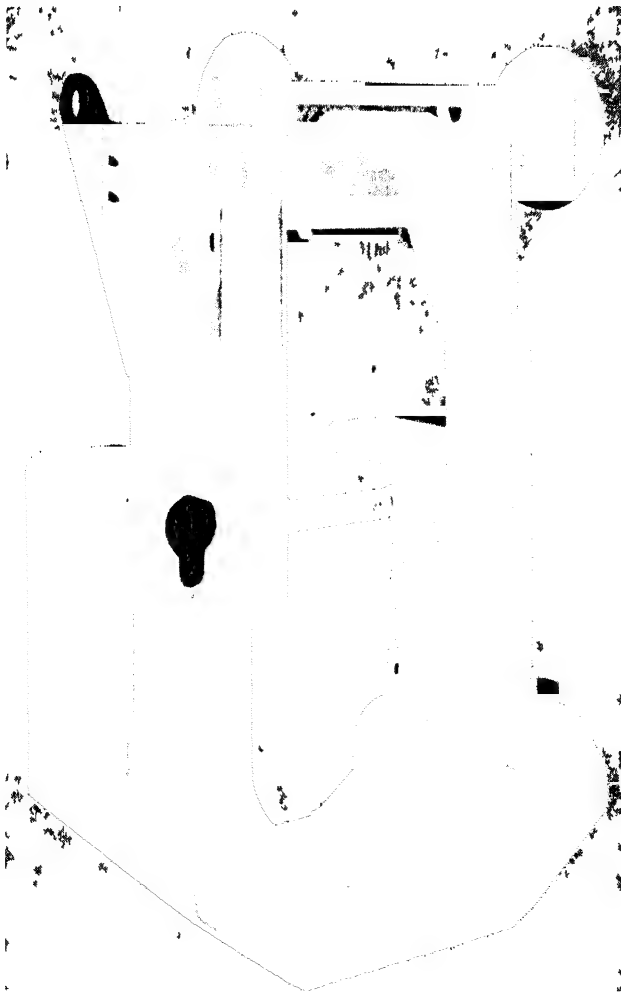
Fig 8. Springs mounted in frame.

conform to the general design of the machine as a whole in a manner to easily promote an attractive exterior.

With the machine width established at 35 inches to permit traveling through a three-foot passageway, the problem is one of apportioning the available space so as to provide for the functional demands. It is, of course, axiomatic that the design must be not only functionally sound but practical to produce. For production reasons, the frame side members should be kept parallel. The distance they must be separated is such as to contain the flywheel housing and related accessories. Nineteen inches was the width determined. The next factor to receive consideration was tires. For the expected load, a need for 10 inches is quickly and definitely settled by reference to manufacturers' capacity rating table.

The mounting of the mast provides for its backward and forward tilt
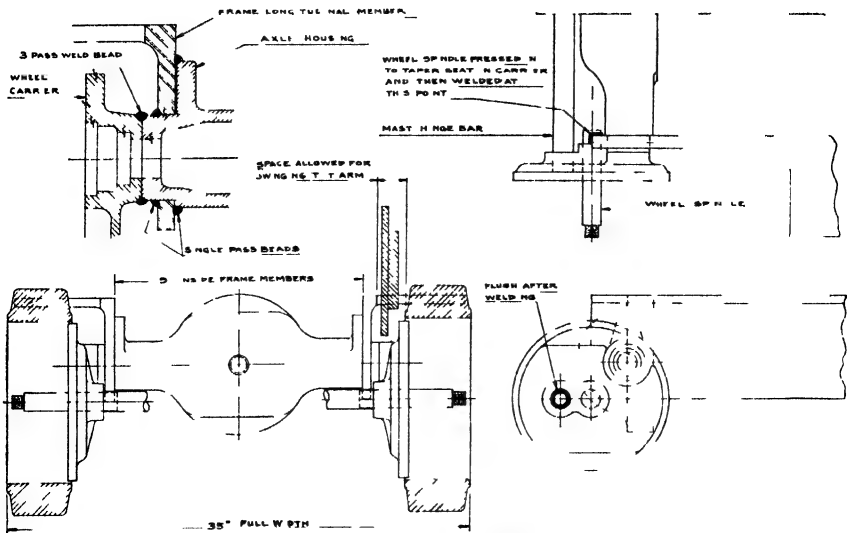
Fig. 9. The final design.

Fig. 10. Frame showing front and side.
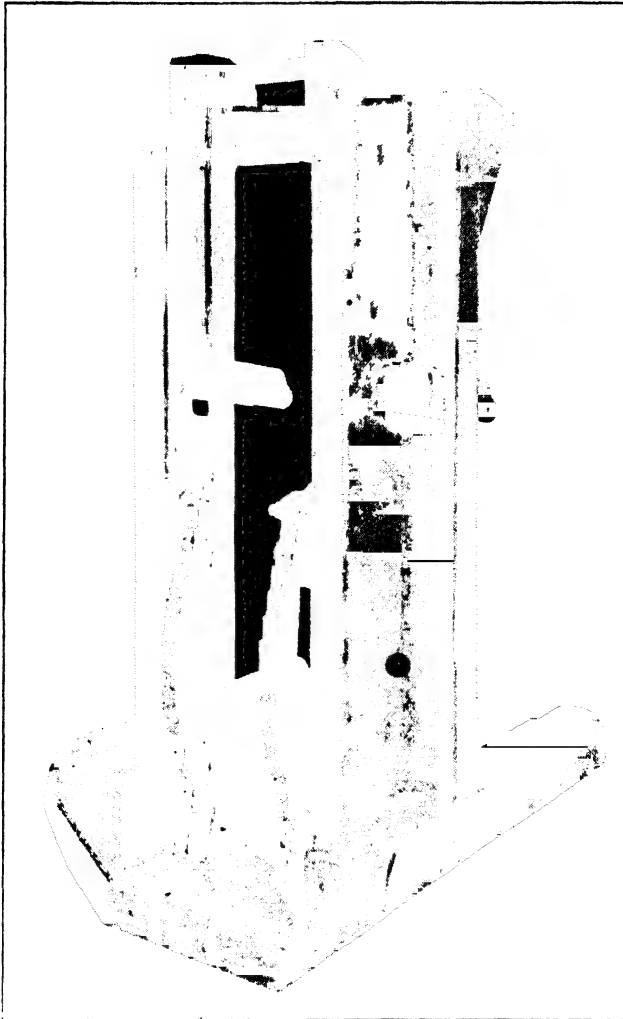
Fig. 11. Frame construction from underside.

in order to properly handle the load This tilting movement is by means of hydraulic operated cylinders attached to the frame These actuate the mast through side arms located between the frame and the wheel. Structural requirements for these arms and clearance space require 1¾ inches on each side or a total of 3½ inches. There now remains from the original 35 inches only two and a half inches in which to provide for two rugged side members, and proper attachment of the frame to the axle structure.

The problem was further complicated by the keen desire for short overall length of the machine. For efficient counterbalancing of the load, it is necessary to locate the carriage as close to the wheels as practical. The mast must be located between the wheels and hinged either on the frame or on the axle. There are, therefore, three elements clamoring for space at the same point: a, the axle for cross beam and gear housing space; b,

the frame for a rugged cross member; and c, the mast for a suitable hinge.

The design, as it eventually worked out is shown in Fig. 9. Fig. 10 is a photograph of the frame, showing its front and side at this point. Fig. 11 is a photograph showing the construction from the under side. Fig. 12 depicts, in perspective, the factors for which provision must be made and the progressive build-up toward the sturdy, rugged unit that the frame becomes as the detail parts are electrically arc welded together.

Referring to Fig. 12, at the upper left hand corner is shown the gear train, the shafts of which must be journalled with precise and permanent accuracy. Below in Fig. 12, is shown the typical automotive bevel gear differential carrier, adjacent to which is shown a housing setup that might (but
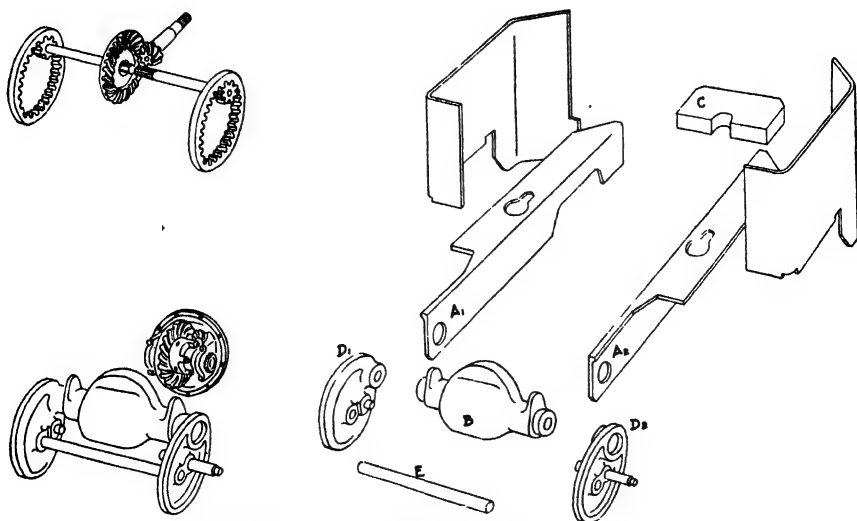
Fig. 12. Perspective drawing of important factors.

does not) serve as a separate axle structure. At the right in Fig. 12, is shown, in related position, the frame elements. Basically, the frame consists of four pieces. The two longitudinal members—A-1 and A-2—are made from common 8x8x5/8-inch structural angle. Note how the flange sections are cut to form clearance space for the wheels. The keyhole shape in the top flange is for the hydraulic tilt cylinder. The holes at the extreme left are bored to fit the turn pilots on the end of the axle housing B. As the distance between the shoulders on this cast steel housing and the length of the rear cross member—C, are both nineteen inches, the setup of the frame for welding is extremely simple. Inserting the housing pilots in the bored holes—making sure that the finished face of the housing is in proper angular relationship with the top line of the frame—locating the three-inch thick rectangular block C at the rear in its proper position—clamping the parts together, the job is ready for welding. Fig. 9 shows the weld beads both inside and outside of the angle web, as the parts are joined at this point.

The alignment of the wheel carriers (D-1 and D-2) with the housing (B) is by means of a combination alignment and clamping bar, which fits the accurately reamed holes in the above parts. Before welding, the carriers

are properly positioned relative to each other by inserting the mast hinge bar (E). All three are now brought into proper relative position to the top of the frame, tightly clamped and welded. This second stage of the welding process must be performed with care, as on its relative accuracy depends the quietness and life of bearings and gears.

Considerable credit must be given to welding engineers for encouraging us to proceed along these lines and in helping us to make it a success. The balance of the welding job on the frame is quite conventional and requires no comment.

While we feel that the factor of production costs is of minor significance as compared with performance characteristics of the machine, cost records show an appreciable saving. The table given below deals only with those factors directly involved and does not show total costs.

	Old Design	New Design
Axle structure	$ 57.20	$46.12
Bevel gear housing unit	59.25	40.60
Frame structure	22.58	3.13
*Welding on Frame @ 14.3¢ per ft.	2.46	1.19
Assembly Details—bolts, etc.	1.60	00000
	$143.09	$91.04

Or a saving of 36.4%

*The average cost of depositing a single pass 1/4 inch or 5/16 inch fillet weld bead is 14.3 cents per foot on this sort of work, in our plant at this time.

It is, therefore, apparent that on the 329 machines produced in the eighteen months since the introduction of this model, there has been a saving of $17,124.45 to the manufacturer. With increased production to meet growing demand, this saving will be augmented.

A more important factor is the saving to the users of the machines. To quote a few specific examples:

1—"One man with this machine regularly unloads 150 to 175 tons of wood pulp from freight cars to storage per eight hour day, in place of 5 to 15 hand truckers."

2—"Manufacturer of concrete blocks, with a single machine, holds to a production schedule of 600 blocks per hour, carrying 72 blocks (1872 pounds) from machine to kilns—kilns to yard—and returns the empty racks to the block machine. This job cycle, covering 300 to 350 feet, averages seven minutes and twenty seconds."

3—"The ability to store in an accessible manner material to a height of 15 feet removed the necessity for the construction of another storage warehouse, the projected cost of which was $120,000."

War effort is largely a matter of moving material. That effort is now absorbing our entire output. The government is putting up a new plant to greatly increase our production. How to compute the dollar value now or to estimate its future sphere in peace time is beyond my power. Suffice to say, the process of electric arc welding has here shown—as in so many other cases—value beyond measure.

Chapter VII—Streamlined Fire Truck

By James W. Fitch,

Automotive Engineer, Kenworth Motor Truck Corp., Seattle, Wash.

James W. Fitch

Subject Matter: Design and construction of a streamlined fire truck of welded steel to accommodate equivalent equipment in a 28-foot length that formerly required a truck 62 feet long. All parts are enclosed to minimize hazards of city traffic and room for 7 men is provided in the cab. The required light weight, strength and stiffness were accomplished by welded construction. Other methods of construction would be more expensive and impractical.

The long, undulating, weird sound of the siren puts everyone on the alert these days. From childhood to manhood, man has learned to recognize this danger signal. When a child, the siren sound may have brought delight, because it was a chance to see the old steam, horse-drawn fire engine come thundering down the street. Today, this same siren sound still causes much excitement. But instead of seeing the horse drawn fire engine of years ago, the spectator now sees a streamlined engine that is a far cry from the steamer of old.

This trend in modern design has been caused by many things, chief among which is the growth of our cities. As the population increased and more people migrated to the cities, a congested condition was soon evident. This was augmented by the improvements in motor transportation. With the mass production cycle in the automobile, truck and bus, the congestion in city streets became worse and worse. Many fires were out of control before fire apparatus could arrive because of traffic conditions. It has often been said that any fire could be put out with a bucket full of water if put on soon enough.

Many foresighted fire chiefs recognized the danger involved by trying to fight fires with apparatus that was no longer suitable for the job.

This resulted in the design of modern streamlined apparatus that could be rushed through congested areas in a minimum of time.

Change in the design of fire apparatus was not easy. Like many other worthwhile improvements, this new design had to prove itself. Many were reluctant to try, because of the increased cost of modern apparatus.

The idea of modern fire apparatus, (See Fig. 1), would probably have "died in the bud", so to speak if it were not for the men who dared to excel in new enterprise. In this particular case, it was a matter of applying welding to the manufacture of fire apparatus.

The changing of a basic design in the modernized vehicle industry is usually a costly one. When this change is made on an item that will not be produced in quantity lots, then the cost almost prohibits the manufacture

of this item. So it was with us Our first estimates included pattern cost, castings, layout for riveting and bolting and the costs were extremely high. It was doubtful whether we could make a piece of apparatus for a reasonable price It was necessary, then, to attempt a new kind of construction that eliminated many of our overhead costs

Second, it was necessary to reduce the size of the apparatus into a closed compact unit, (See Fig 2) This also indicated welded construction
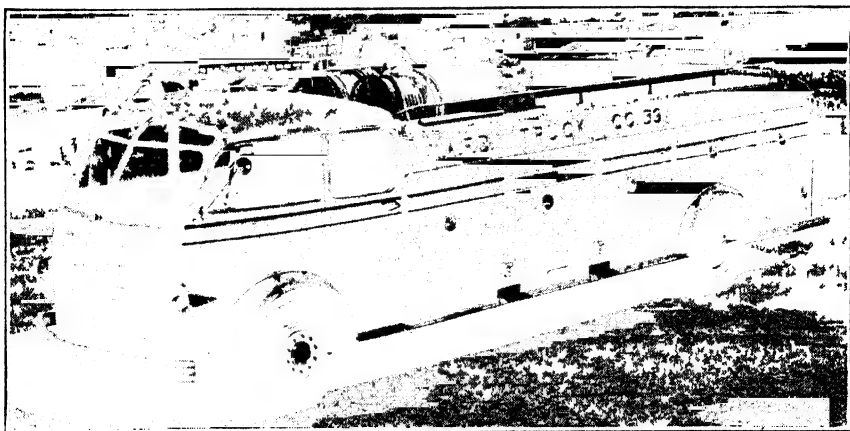
Fig. 1. The last word in modern efficient fire-fighting equipment.

This particular type of truck was to be known as a triple combination city-service truck, which we will hereafter refer as to a "T C C S T" The truck was to do the work that was formerly done by a truck and trailer that was approximately twice as long It was not only asked to replace this tractor-truck but it was to do so with better performance and maneuverability The overall length was to be cut from approximately 62 feet to 28 feet The new apparatus was to house a crew of seven men in the cab whereas the old apparatus provided room for only three men in the cab The remainder were required to find a place wherever possible. Provisions had to be made to enclose all equipment from weather and dirt

In order to arrive at a satisfactory design in modern fire apparatus, it was necessary for us to use a pancake engine This gave us a very compact frame construction, and also gave a more compact unit as well as a low center of gravity

Considering the various points outlined, a welded design was attempted and was based on the following assumptions of what welding would do:

1, Save pattern costs, 2, Give a more flexible design, 3, Allow streamlining body appearance, 4, Enable us to speed the delivery date of the vehicle, 5, Save weight which would mean better performance, and 6, Provide for a safer unit

With these points in mind, the preliminary drawings were made In some places, welding was not practical and conventional practices were followed. This was especially true where parts were required to be removable or were heat treated In both cases, however, many of the component parts were welded.

Social Advantages—Oftentimes a split second may be the deciding factor in saving a life It is the saving of this precious time that has prompted the

design of this vehicle. The clear visibility from inside the cab gives the driver a commanding view of the road at all times. Plexiglass windows are used over main windshields. The apparatus is, thus, able to respond to an alarm with the maximum of safety, especially where the traffic is congested and the streets narrow.

By welding the body and chassis together, a mono-unit type of construction is accomplished.

Without this type of construction, the chassis frame would have to be increased in weight approximately 50 percent.

Although no accurate analyses have ever been made because of indeterminate stress distribution in the body, experience has given us a fair indication of this stress distribution. Any critical stress in the frame that may cause a part to reach the elastic limit is transferred to the body. The body acts as a large tube which is able to absorb the stress without harm. This welded type of construction also assures us of a torsional resistant structure for the same reason. Because of this rigidity, the wear and tear on such parts as radiator, engine, engine supports, brackets, tanks and equipment is reduced to a minimum.

The total cost of this type truck exceeds the cost of the conventional truck, but the advantages of the modern truck more than make up for the price differential. It is the opinion of many fire chiefs that the trend in fire apparatus is truly to this type of equipment. This belief is substantiated by fire equipment that is now being produced. We feel that we have contributed a fair portion to this development.

Superiority of Streamlined Truck—The Kenworth streamlined "T.C. C.S.T." provides a new high in fire-fighting equipment efficiency. It also provides better protection for the fire-fighting crew.

The streamlined body is compact with no protruding parts. It is possible to operate the truck without fear of hanging up on a pump nozzle or ladder hook. The clean, smooth welded surface of the body provides the utmost safety against cuts and bruises that may result from operating a conventional unit.

All equipment is enclosed and arranged in accordance to its use. Each compartment is provided with a quick-opening handle, which automatically turns on a light inside of the compartment. All compartments are labeled so that equipment can be easily located. All equipment can be kept well arranged, clean and in good operating condition.

Cab forward offers best visiblity in all directions and is especially significant when making a turn. In the cab-forward truck, the driver can execute the turn without having half of his truck out in the middle of the street as is the case with the conventional truck.

Large safety glass windows all around give ample visibility in all directions. Plexiglass observation windows directly over the windshield give ample overhead visibility when approaching a fire.

The forward compartment provides storage for hose that can be drawn from either the right or left hand side of the truck. This adds versatility and efficiency in fire fighting.

The pump compartment contains a separate panel properly illuminated for all gauges and other instruments used in operating the pump. All controls are effectively located for efficient operation. Rear suctions are provided for operation on narrow streets or wharves.

Motor pump, water and fuel tanks are mounted amidship, and at a low height above the ground. This effects a low center of gravity, as well as a

better balanced truck, and makes possible maximum stability and best riding qualities under all conditions. This fire truck can be operated without fear of overturning, because of top-heaviness. Even weight balance assures greater safety in making turns on slippery roads, because of the increased traction on the turning wheels.

The Kenworth streamlined truck makes possible a shorter wheelbase (approximately 5 feet shorter than conventional models). This assures greater maneuverability heretofore impossible with the large, bulky, long-wheelbase fire truck. The Kenworth fire truck eliminates possible accidents from running over curbs or traffic buttons. It makes possible greater safety at faster speeds through congested traffic. The Kenworth fire truck has approximately 9 feet shorter turning radius than other conventional fire trucks of the same capacity.

This fire truck is monocoque-constructed, that is, the frame is made integral with the body. This assures the lightest weight with the most strength. The light weight assures better performance at lower cost.
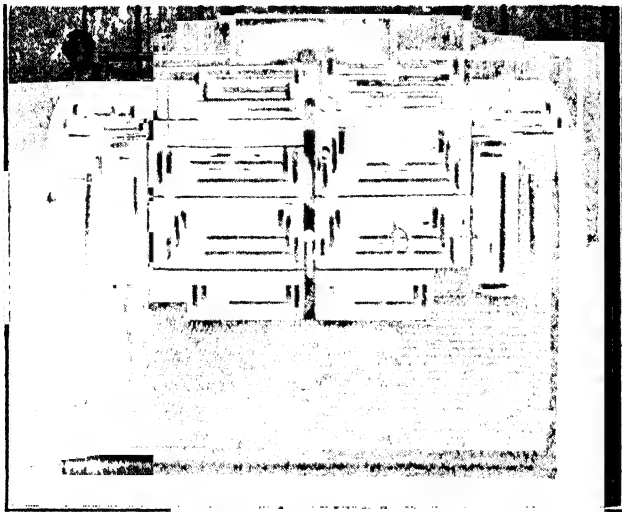
Fig. 2. Rear view showing over 400 feet of ladders.

Cost Data—Welding—The welding cost is broken down into two parts as follows:

1. Chassis: The all welded parts of the chassis are as follows:

2 Front spring brackets
Gussett
Steering gear bracket
Auxiliary tube support
Front shackle bracket
Rear spring bracket
Boost tank
Miscellaneous brackets
Rear suction pipe
1 Air tank hanger
2 Compressor hangers
3 Pump controls
2 Front engine cross-members
2 Rear engine brackets
Exhaust pipe
Frame
Out rigger

The main parts of the chassis are shown in Photos, Figs. 3, 4 and 5. This amounts to approximately 112 feet of ¼-inch fillet welds.

2. The welded parts of the body are:

Body structure and skin	1500 inches
Compartments	500 inches
Ladder racks	500 inches
Miscellaneous welding	500 inches
	3000 inches

Approximately 250 feet of ⅛-inch weld.
This amounts to a total of 362 feet of ¼-inch and ⅛-inch welds.

Welding Costs

Welding crew:

Fitter	$1.00 per hour
Welder	1.00 per hour
	$2.00

Total Welding cost:

Time required at 5 feet per hour average	72.4 hours
Layout time	40.0 hours
	112.4 hours
	at $ 2.00 per hour
	$224.80
Cost of material at .06¢ per pound—200 pounds	12.00
	$236.80
Plus 25% overhead	59.20
	$296.00

1. Cost Data—Other Construction

	Pattern Cost	Weight pounds
Front spring bracket right and left	$ 25.00	20
Steering gear bracket	15.00	15
Auxiliary tube support, including brackets	25.00	30
Front shackle bracket	25.00	50
Front engine cross member	35.00	30
Rear engine brackets	40.00	40
Rear spring brackets and cross member	35.00	40
Rear suction fitting	50.00	40
Air tank hangers	20.00	20
Pump controls	40.00	25
Compressor hanger	25.00	20
	$335.00	330

(The above costs based on similar parts previously cast.)

2. The additional machining required on castings is usually a grinding operation or, in some cases, a shaper operation. Because rolled plate is used in the welded parts. These operations are seldom necessary. This amounts to four hours, based on actual experience.
3. Additional cost of material, (estimated weights), when castings are ordered in quantities the cost average is 12 cents per pound. The material cost amounts to $39.60.
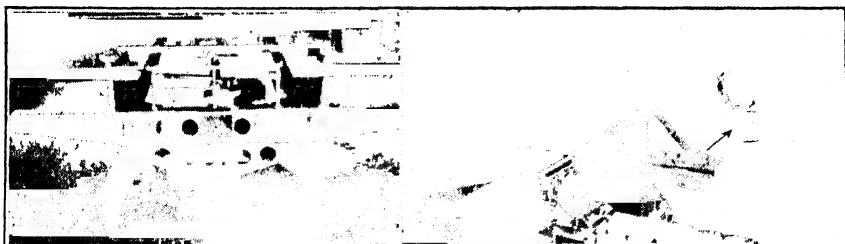
Fig. 3, (left). Frame parts at front end clamped for welding. Fig. 4, (right). Welded brackets at rear of frame.

4. Assembly Crew:

		Time required		
Bucker	$1.00	Chassis	24 hours	
2 Helpers @ .80¢	1.60	Body	48 hours	
	$2.60		72 hours	

Cost Estimate by other means of Fabrication

Pattern cost	$335.00	Eliminating Pattern Cost =$267.25
Material cost	39.60	
Labor	187 20	Plus amortization of patterns for 10 trucks = 33.50 per truck
	561.80	
Plus 25% overhead	140.45	$300.75
	$602.25	

Comparison of Fabrication costs

Non-welding fabrication	$602.25
Welding fabrication	296 00
Gross saving by welded construction	$306.25

With overhead applied to carrying stock pattern, etc. The cost would be approx. the same for both types of fabrication.

This is 49 percent of the non-weld construction.

In addition to this, the cost of additional support and braces would have to be figured. The castings riveted or bolted to the structure would not suffice because of the rigidity required in the frame. This is particularly true on the front part of the frame, (See photo, Fig. 3). Here the welded construction ties in the frame rails, radiator supports, front spring drive brackets, steering gear bracket, auxiliary tube supports, and also acts as a body outrigger.

It is difficult to determine how this particular assignment can be accomplished by any other means of construction. Therefore, no monetary estimate can be given. This particular advantage is carried out in many places, because only in this way can a compact unit be made.

Within a wheel base of 220 inches and an overall length of approximately 28 feet, this unit carries the equipment that would ordinarily have to be carried by two trucks. The two trucks would have a combined wheel base of some 400 inches, and would be approximately 62 feet long.

Thus, welding not only makes the unit more compact, but also makes possible the points of superiority listed previously.

The following examples give a general cross section of the various parts used on this particular model. These small pieces were chosen because they were drawn on a convenient size for use in this article.

Hand Brake Bracket

Non-Weld Construction		Weld Construction	
Pattern cost	$12.00	Welding cost 15 feet assembly	$1.00
Material	2.00	Material cost	1.00
Machining	3.50	Machining	1.00
Layout	1.00	Layout and shearing	2.50
	$18.50		$5.50
Second piece cost	7.00		

Welding cost figured at 4 feet per hour @ $1.00 per hour.

Saves 70% for one piece. Saves 20% for more than one.

Overhead figured the same on both parts.

Front Spring Drive Bracket

Pattern cost	$12.00	Welding	$1.00
Material	4.00	Material	2.00
Machining	10.00	Machining	8.00
Layout	2.00	Layout	3.00
		Bending and Shearing	2.00
	$28.00		$16.00
Second piece cost	$16.00		

Saves over 40% for one piece. Cost equal for more than one piece.
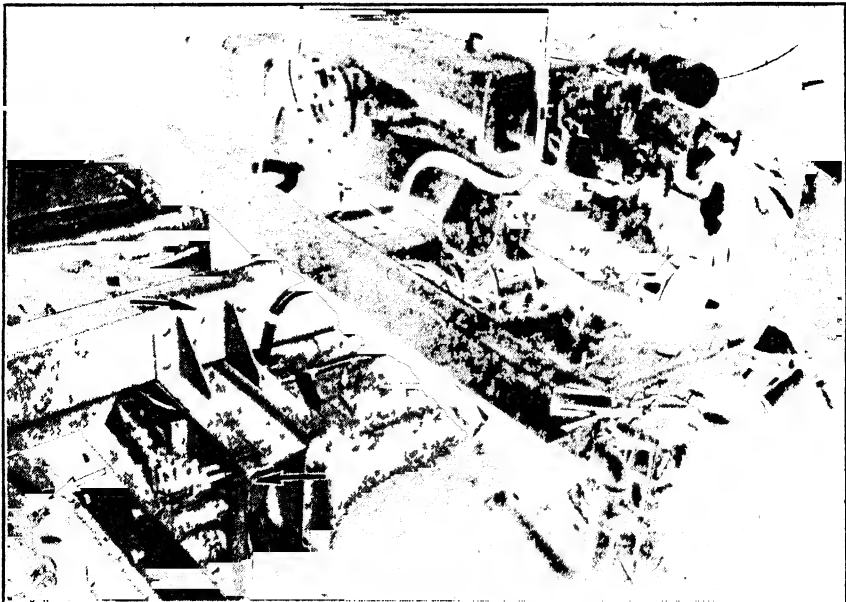
Fig. 5. Welded frame construction.

Fig. 6. Advances in fire apparatus—right, 1900; center, 1920; left, 1940.

Transmission Case Mounting

Riveted Construction

Riveting time 2 hours	$5.00
Material	1.75
Machining	2.50
Layout and Shearing	6.00
	$15.25

Riveting crew $2.50 per hour

Riveting would require additional plates and flanges and general re-design of part. This would make the piece heavier and bulkier and not as rigid.

Welding	$2.00
Material	1.75
Machining	2.50
Layout and Shearing	2.50
	$8.75

Saves over 40% over rivet construction in this case.

The above percentages do not take into consideration the decrease in cost of welded parts for quantity production or even 10 parts. Welded parts cost based on 1 unit.

Exhaust Valve Shift Lever

Non-Weld Construction

Pattern cost	$12.00
Material	1.00
Machining	3 00
Layout	1.00
	$17.00
Cost of second piece	6.00

Weld Construction

Welding	$1.00
Material	.50
Machining	1.00
Layout	1.00
Bending and Shearing	1.50
	$5.00

Saves approximately 70% for one piece. Approximately equal for more than one piece.

Therefore, it can be said that for first models or experimental models, welding is by far the most economical method of construction. Even when the pattern cost of the pattern is amortized over ten to twenty castings, the cost of the welded part compares favorably. This does not take into account the other advantages derived by using welding as outlined elsewhere in this paper.

Compare the modern welded truck with the old type in Fig. 6.

Chapter VIII—Wheel Mounting for Racing Automobile

By E. W. Jacobson and F. F. Versaw,

Design Engineer and Shop Superintendent, respectively,
Gulf Research and Development Company, Pittsburgh, Pa.

E. W. Jacobson

Subject Matter: Construction of a welded steel wheel mounting for a four-wheel drive racing automobile. Two radius arms support the wheels transmitting shock loads to the mounting. Highly stressed, chromium molybdenum, SAE X-4130 steel used to reduce weight. Since no differential was provided, additional stresses would come on the steel mounting. Considerable saving in cost over cast steel construction, together with far more satisfactory performance result.

F. F. Versaw

This paper describes how use of arc welding solved a very difficult design problem in the wheel mountings of a frame for a racing car. The nature of the problem was such that only by using arc welding could a satisfactory design incorporating the necessary lightness, extremely high strength, compactness, and reasonable cost be achieved.

The authors hope that the procedure outlined will prove to be a valuable guide in fabrication of similar highly-stressed structures not only in the field of special-purpose automotive frames, but possibly in aircraft parts where light weight and high strength are of prime importance.

The arc welded wheel mountings were a vital part of two special race car frames, (See Fig. 1), designed to mount a pair of high-output, high-speed automotive-type engines for use in the Indianapolis Memorial Day auto races.

Figs. 2 and 3 show views of a right front wheel mounting bracket. Fig. 4 shows the parts which were arc welded together to form this bracket. Fig. 5 shows the parts before assembly into the frame. Fig. 6 shows the completed frame. Fig. 7 shows a front view of the completed chassis. Fig. 1 shows the rear view of one of the completed racing cars.

These engines were mounted in four-wheel drive chasses with individually sprung wheels. On the frame first used with this type engine, the fuel tanks had been mounted outside the main frame side channels. For the 1941 race, the speedway officials ruled that these tanks must be protected either by mounting within the boundary of the frame or inside of the frame side rails themselves.

The frame design selected was that using a box girder section side rail, housing two fuel tanks, one just forward and one just behind the center crossmember with the arc weld-fabricated wheel mountings in each end of these box-girder side rails.

The design which this replaced used a channel-shaped side rail with steel casting wheel mountings at either end of each rail. The new frame was required to have a weight comparable to the old simple side rail design and to provide mountings for the wheels, engine, etc., which were already made.

The new arc weld-fabricated wheel mountings herein described were the most vital part of this box-girder frame.

The stress picture in the wheel mountings was complicated by several factors. Each of the front wheel mountings was bolted directly to an aluminum differential case which tied the front of the frame together. The rear wheel mountings were bolted to the transmission case which was integral with the engine assembly. The wheels, all four of which were individually driven, were suspended from the wheel mountings by two radius arms each. These radius arms, which were supported by needle-bearinged pivot shafts in the arc welded mountings, carried all the stresses arising from the wheels, directly to the wheel mountings. These transmitted stresses arose from any one or a combination of the following: 1, torsional load arising from application of the wheel brakes; 2, horizontal bending and thrust loads due to the wheels driving the car forward; 3, horizontal bending and thrust loads due to the wheels slowing up the car when the brakes were applied; 4, horizontal bending and thrust loads due to the wind-up between the front and rear wheels when going around curves. There was no differential action provided between the front and rear wheel drives, so that when on curves the wheels, each rolling on a different radius, would turn at different rates for short periods. This tended to produce forces which would try to change the center distance between the front and rear wheels to compensate. The forces would build up until tire slippage relieved them; 5, the inner ends of the two cantilever springs on each wheel placed high stresses in the spring support pads; 6, each upper radius arm pin was keyed to the radius arm and was lever-connected to a hydraulic shock absorber, which in turn was fastened on the wheel mounting. (See Fig. 7); 7, each lower radius arm pin was connected to a friction-type shock absorber which was also bolted on the wheel mounting. (See Fig. 7); 8, the front brackets carried the steering gear supports and thus absorbed all the steering loads; and, 9, the rigidity and stiffness of the box-type frame section tended to centralize the shock loads in the highly-stressed sections of the wheel mountings.
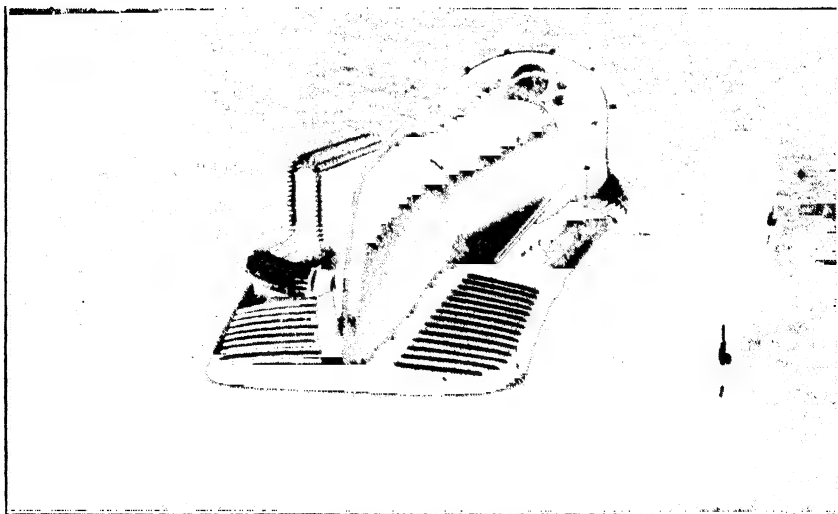
Fig. 1. Rear view 1941 race car.

Fig. 2. (left). Right front mounting bracket. Fig. 3. (right). Another view of the right front mounting bracket.

It was quite evident from the stress analysis of the possible combinations of the above loads that material of extremely high strength would be required if the weight was to be kept within reasonable limits. It was also apparent that the choice of fabrication lay between arc welding or cast construction if the piece were to adapt itself to mounting of the mechanical parts already made. The complicated nature of the wheel mounting required by the many fastenings for other parts, coupled with the low weight requirement necessitated material thickness of not greater than ⅛-inch for the most part, with thicker sections only allowed where extremely high stresses required.

Cast construction was abandoned in favor of arc-welded construction because of the following reasons: 1, the complicated nature of the bracket made possibility of securing reasonably sound castings improbable, if not impossible; 2, experience with the steel castings used in the simple previous
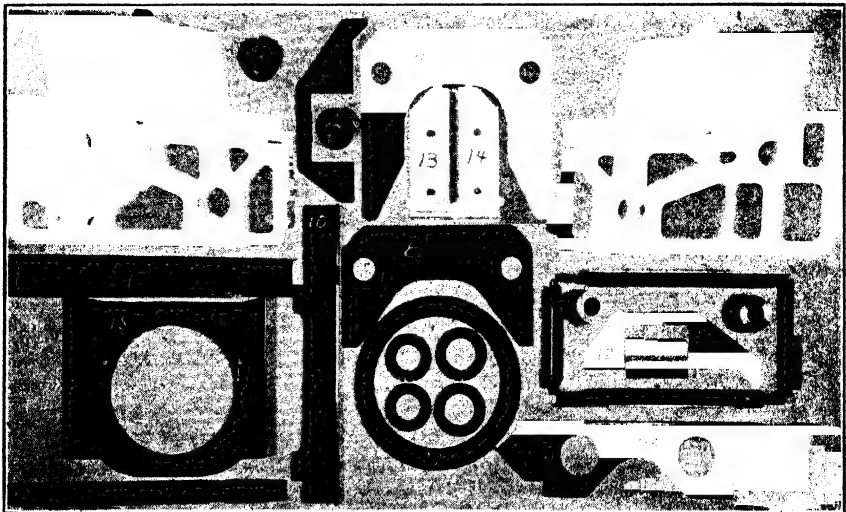
Fig. 4. Parts for radius arm mounting bracket.
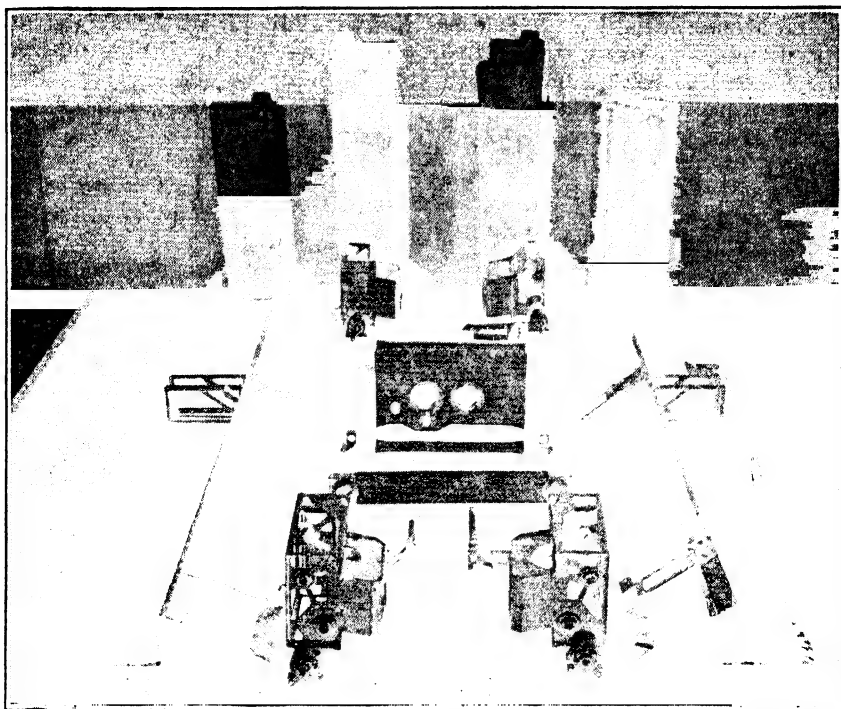
Fig. 5. Frame parts.

design had been partially unsatisfactory; 3, there was not enough time to experiment with steel casting methods; 4, strength tests on cast metal could not be made satisfactorily, without actual destruction of a casting. Tests on one casting would not insure that the strength of another similar casting would be satisfactory; 5, only by use of arc welded construction would it be possible to stress sections close to the safe calculated limits to keep the high strength-weight ratio required; 6, by use of arc welding, physical tests of sample weld specimens would give close criteria of safe working loads; 7, the cost of a pattern of such a complicated steel casting would exceed the arc welded fabrication cost of the small number of wheel brackets required; and, 8, a high-strength alloy steel which could be satisfactorily arc welded and heat-treated was available in SAE X-4130.

Chromium molybdenum SAE X-4130 steel was selected because of its excellent welding properties, high impact-to-tensile-strength ratio, its receptiveness to heat-treatment, and its ready availability. Fig. 4 shows the 25 separate pieces which were shaped from SAE X-4130 sheet stock and bar stock to make up the wheel mounting brackets. Most of the pieces were 1/8-inch thick while some were made from 3/16-inch thickness where required for strength. The spring support pads, parts 13 and 14, were made from 3/8-inch-thick bar and the radius arm bearing bosses, parts 3, 4, 5 and 6, were made from 1 1/2-inch-diameter bar stock. All the sheet stock was used in the as-rolled condition. Bending and forming operations on the sheet stock were made at an elevated temperature, the parts to be formed being heated to a low red heat to prevent cracking at right angle bands, with excellent results.

Electrodes in the ⅛-inch-diameter size were used in all the arc welding operations. This rod was selected because of its smooth welding qualities and response to heat treatment like SAE X-4130. Before welding was started, two standard A. S. T. M. welding samples were made from ⅛-inch x 1-inch stock. These pieces were joined by 60° V-groove butt welds, the pieces first being preheated to 400° to 600° F., and allowed to air-cool after welding. Following welding, these samples were machined to ½-inch width at the weld and the excess weld material removed. They were then pulled in a tensile machine with the following results:

	Tensile Strength	Elongation in 2 in.
Sample 1	90,880 p. s. i.	2.5%
Sample 2	107,200 p. s. i.	5.5%
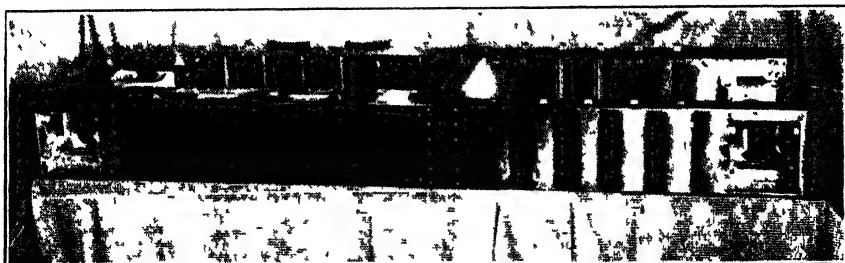
Fig. 6. Completed frame.

These tensile strengths were considered satisfactory since tensiles of only 70,000 to 80,000 pounds would normally be expected in such welds without heat-treatment subsequent to welding. The elongation was somewhat lower than desirable, but this would undoubtedly be improved by proper heat-treatment after welding. Following these tests, it was decided to use V-groove welds only where high strength was required. Plain fillet welds were used where stresses were low. Single-pass welds were used throughout.

Very simple fixtures were used to hold the parts in place for welding. Two hollow spacer bars and two 1-inch threaded rods were used to hold the side plates, items 1 and 2, in position. The rods were run through the radius arm bearing bosses, items 3 and 5, and 4 and 6, and pulled up with the spacers between. This simple assembly was clamped to a surface plate as required throughout the assembly operations to insure proper alignment. Individual parts were held in place for welding by clamps as required. Locating pins were used to assemble the spring pads, items 13 and 14, as they had to be machined before assembly, and their location was quite critical.

The order of assembly and welding of the parts after preheating to 400° to 600°F. before each weld was made, was as follows: (See Figs. 2, 3 and 4).

1. Spring pads, items 13 and 14, were assembled on the side plates 1 and 2. The locating pins were peened over to assure proper location and a screw was used to hold the inner ends in place. These parts were not welded in place until later.

2. Assemble and weld reinforcing rings, items 16 to plate 1 and items 17 to plate 2.

3. Assemble the inner radius arm bearing bosses, items 3 and 4 in plate 1, weld inside to plate 1 and outside to reinforcing ring, item 16.

4. Assemble outradius arm bearing bosses, items 5 and 6 in plate 2. Weld inside to plate 2 and outside to reinforcing ring, item 17.

5. Assemble spring pad support plates, items 11 and 12, and weld both sides to side plates, items 1 and 2.

6. Assemble side plates 1 and 2 with the spacer bars and rod bolts in position and clamp this assembly face downward on a surface plate for alignment.

7. Assemble reinforcing plates 7 and 8 and weld in position, both sides, to items 1, 2, 3, 4, 5, 6, 11 and 12.

8. Assemble back plate, item 15, and weld to side plates, items 1 and 2; then to reinforcing plates, items 7 and 8; then inside to spring pads, items 13 and 14. Complete welding of spring pads to side plates, items 1 and 2.
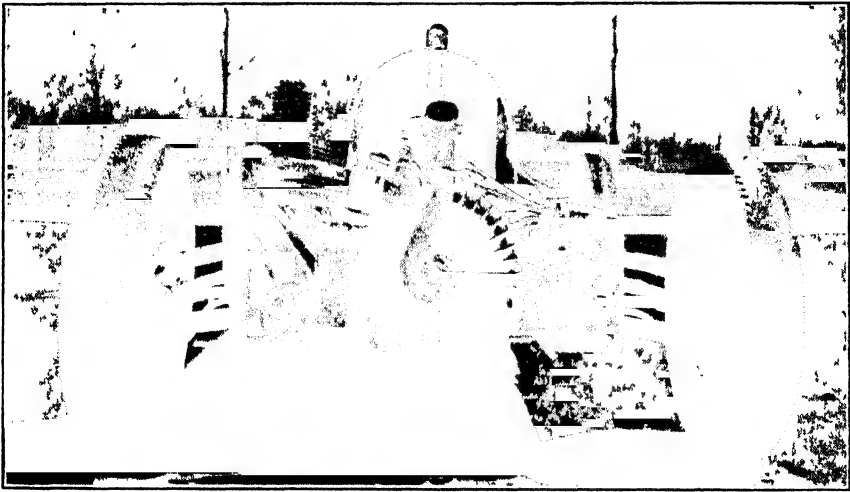
Fig. 7. Front view race car.

9. Assemble inside top angle plate, item 18, in position and weld to side plates, items 1 and 2, then to item 7, both sides.

10. Assemble lower inside angle plate, item 10, and weld to items 1 and 2, then to reinforcing plate, item 8.

11. Assemble upper outside angle plate, item 19, and weld to side plates, items 1 and 2.

12. Assemble lower outside angle plate, item 20, and weld to side plates, items 1 and 2.

13. Assemble steering support angle section, item 9, and weld to items 10, 18, 19 and 20.

14. Assemble spring pad support stiffener, items 21, and weld to items 11 and 12, 13, 14 and 7.

15. Assemble positioning ring, item 22, and weld to item 15.

After welding was completed, the assembly was heat treated. The spacer bars and rod bolts were left in position during the heat treating operation to hold the assembly from distorting. The heat treatment consisted of normalizing at 1,600° to 1,650°F. and drawing at 1,000° to 1,100°F. to secure a hardness within 200 to 225 Brinell hardness number. Sandblasting to remove scale was the next step.

In order to determine the presence of cracks, holes, or general porosity in the welds at the highly stressed parts, X-ray pictures were taken of the welds around the radius arm bearing bosses and the spring pads These X-rays showed excellent welds

All the eight brackets came through the above fabrication and heat treatment with negligible distortion, for the most part less than 1/64-inch Only one or two brackets needed to be filed a small amount to be made to fit The only machining required was a milling machine operation to face and bore the radius arm bearing bosses, a lathe operation to turn and face the positioning ring, item 22, and drilling of the bolt holes for assembly to the frame sections Figs 5, 6 and 7 show clearly the position of finished wheel mounting brackets in the frame of the car
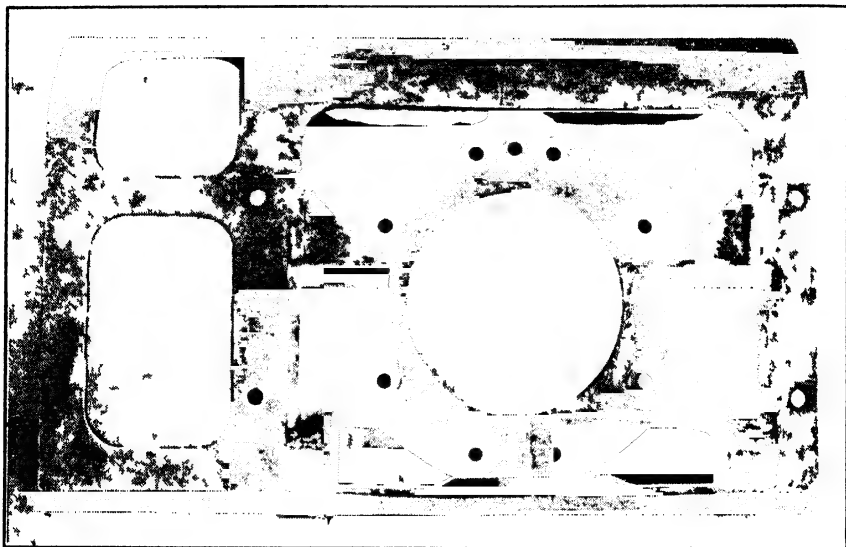
Fig. 8. Original cast steel bracket.

Costs—In the building of the two racing cars, costs of construction was secondary to performance In racing automobiles of this nature, the vital problem is to make all parts just strong enough to meet all the stresses and abuse to which they are subjected during a certain known period of time These cars were built to last out the 500 miles of terrific punishment in the Indianapolis Memorial Day race Elimination of all unnecessary weight was a vital necessity Therefore, materials with the greatest strength-weight ratio were used throughout The materials and methods used in building the wheel brackets described above gave the utmost strength and lightness possible in meeting the very severe stress conditions The success of this type of construction was adequately borne out by the absence of failures or trouble of any kind with these wheel brackets during preliminary testing or in actual racing

As stated previously, cast steel construction was a possibility Fig. 8 shows one of the steel castings used in the first frame design which incorporated a channel section side rail Comparison of the two pieces (Figs 2 and 3 and Fig 8) indicates the greater complexity of the shape of the new

arc welded bracket over the old cast steel design. Had the new brackets been cast, four separate patterns would have been needed. On the basis of the cost of the pattern for the old-type bracket ($311), each of the four new patterns would have cost approximately $350 each, or $1400 for patterns alone. Casting cost for the old-type bracket was $6 each in lots of 24. This many would need to be purchased to be assured of getting eight reasonably sound castings. This cost, then, for castings for two cars would be

Patterns, 4 at $350.00	=$1,400.00
Castings, 24 at $6.00	= 144.00
TOTAL	$1,544.00

The cost of making eight arc-welded brackets was

Material			
400 lbs. SAE X-4130	at 18¢ lb.=$	72.00	
16 lbs. Electrode	at 25¢ lb.=	4.00	
Handling charge, 10%	=	8.00	$ 84.00
Labor			
Fabrication of pieces			
8 units at 22 man hrs. ea. at $1.00 per hr.	=	$176.00	
Welding			
8 units at 16 man hrs.—Welder at $1.00 per hr.	=	128.00	
8 units at 16 man hrs.—Helper at $0.75 per hr.	=	96.00	
Overhead charge, 40% on labor	=	160.00	560.00
Fixtures			
2 bolts and 2 spacer bars (Labor and Mat.)	=		4.00
Power			
150 Kw. hrs. at 2¢	=		3.00
TOTAL COST			$651.00

Heat treatment and sandblasting is not figured in, as practically identical treatment would be given to steel castings as to the arc welded brackets.

The actual cost saving with arc welded construction was, then, $1,544 less $651 or $893 for the eight brackets. This savings in cost was only incidental to the more important factor of increased strength and safety of the arc welded construction over the cast construction.

Were such a complicated piece to be made in quantity production, the pattern cost for a cast steel unit would be charged off to a considerable number of pieces which in turn would bring the unit price way down. However, offsetting this apparent advantage would be the very low cost of punch-press fabrication of the pieces making up the welded unit, and the economies of production-line welding. It is believed that even in quantity production the cost advantage would still be in favor of arc welded construction.

Chapter IX—High-Speed Dirt Movers

By G. J. STORATZ,

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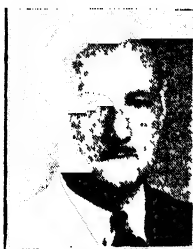

G. J. Storatz

Subject Matter: Construction of an all welded high-speed scoop for earth excavation. The scoop is supported by four rubber-tired wheels and can travel on hard pavement. It is considerably lighter in weight than the former cast steel design. The unit will travel twice as fast as formerly, thus saving cost of earth excavation of $.02 per yard or 50 per cent.

The use of a scraper unit, pulled by crawler tractors, for excavating and grading operations has gained recognition and acceptance to a considerable degree within the past 15 years. The reason for this development is the fact that scraper operations are economically sound, and if properly located, the scrapers will pay for themselves quickly and easily. As a result of this advancement, many interesting developments have taken place in the design of scraper units, and a great many different makes and models are now being offered.

During the past few years, there has been a considerable demand from contractors as well as governmental departments, engaged in projects for the national defense program, for a scraper pulled by rubber-tired tractor units. Their specific demands were for a unit which could be used on long and short hauls with equal efficiency. A growing need has also been expressed for a unit which could operate on, as well as be transported over, the highways. Tractors with cleats are prohibited on all highways. Therefore, a rubber-tired tractor unit will enable road-building contractors to move this equipment over practically any highway. (See Fig. 1).

One of the largest demands for this unit to date has been in the construction of airports where it is necessary, in the course of the work, to run over the present runways. These rubber-tired units can do this without causing any appreciable damage to the runways. With the present national defense program, it has been increasingly necessary to move dirt at high speeds in the construction of large munition plants, army camps and roads leading to and from these camps. As a result of these demands, the scoop was developed during 1941 and is, at present, being used extensively on these projects. (See Fig. 2).

The outward appearance of our newly-designed scraper does not differ greatly from that of the old model. However, the basic changes have been the substitution of high tensile steels for mild steel, and the elimination of practically all steel castings. In fact, the new design uses only six pounds of castings as compared to approximately 3,261 pounds in the former design.

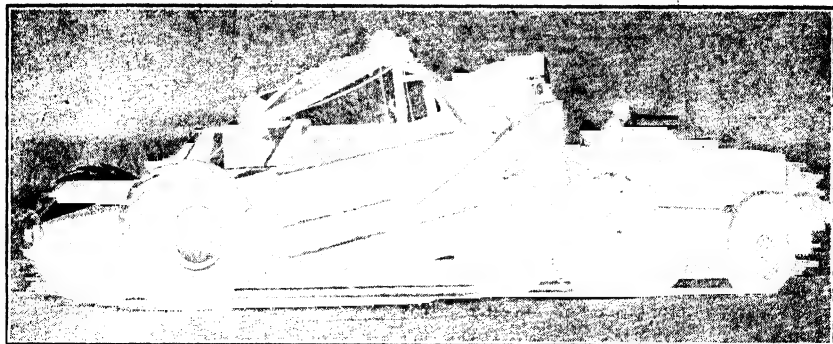



Fig. 1. Side view of high-speed scoop.

Due to the fact that the rubber-tired tractor does not have the traction of a crawler tractor, it was necessary to conserve weight wherever possible. In designing the scoop, it was necessary for us to redesign our former scraper in such a manner that there was a saving in the deadweight of the unit. However, the unit had to be strong enough to carry a load of dirt which would be comparable to a crawler-tractor-drawn unit of the same size.

It was also necessary to keep in mind the economical aspect since, in redesigning this unit, we had to consider keeping the price of the unit in line with our competitors' prices. The high tensile steel could be used only where an appreciable reduction in weight was possible, consequently, our manufacturing costs did not vary greatly due to the use of thinner-gauge high-tensile steel instead of heavier-gauge mild steels. Since practically all of the castings were replaced with welded steel plates, an additional decrease in the weight of the newly-designed unit was achieved.

In following this practice, an appreciable saving of weight was accomplished which, in turn, resulted in a saving in manufacturing cost. In view of the fact that our shop is primarily a "plate shop", it is good economical practice for us to fabricate the majority of our parts of welded-plate design and thereby avail ourselves of our manufacturing facilities.

The weight of a crawler-tractor-drawn unit was approximately 21,000 pounds, and the weight of the redesigned unit was lowered to approximately 18,700 pounds, or a nine per cent saving in dead weight. Both model scrapers were capable of transmitting a net weight of 30,000 pounds.

The following paragraphs will analyze the design of the component parts of the scraper, showing where savings in cost and weight were effected. The component parts of a scraper are as follows—1, bowl assembly. 2, movable floor assembly. 3, rear lift link assembly. 4, front apron assembly. 5, front lift frame assembly. 6, front lift arm assembly. 7, wheel assembly; and 8, push bumper assembly.

Fig. 2. Operating views of high-speed scoop.

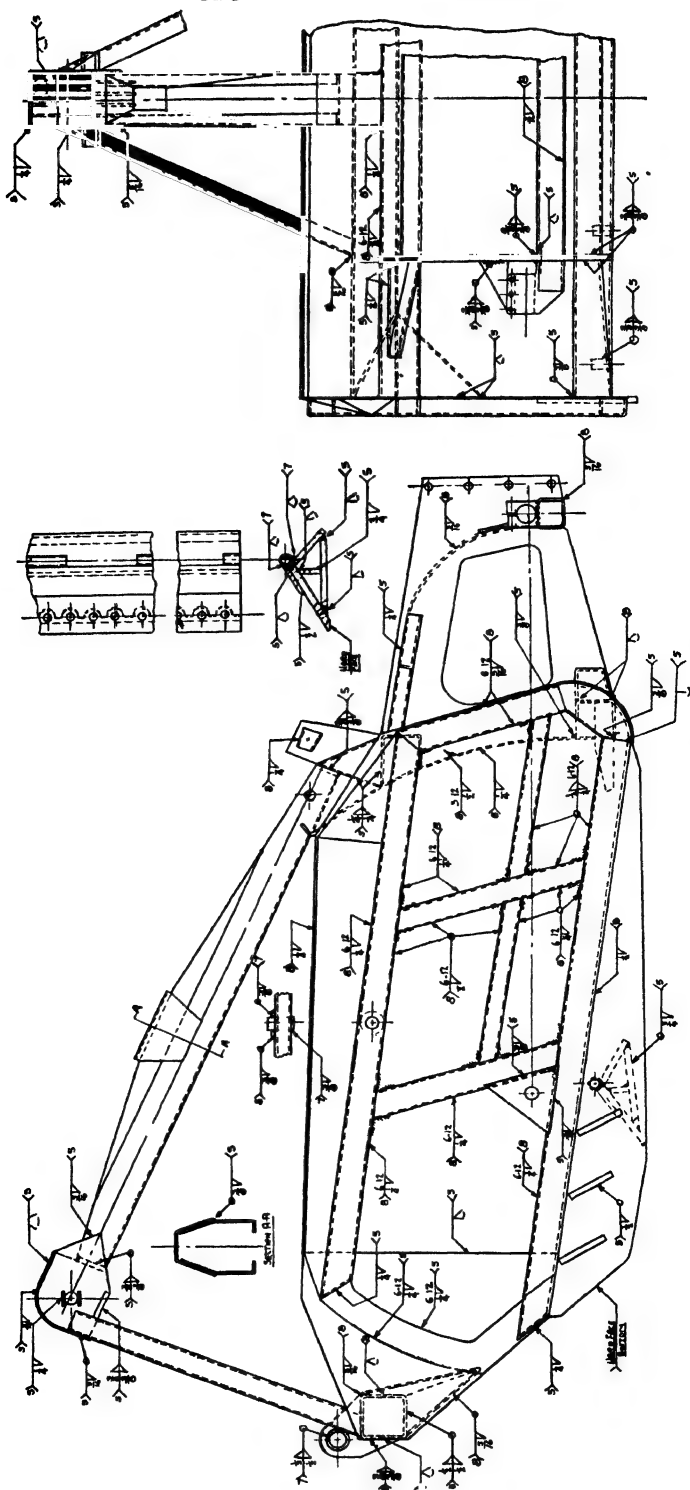



Fig. 3. Bowl assembly.

Bowl Assembly, (See Fig. 3):—The bowl is the main part of the scraper since its function is to carry the load. It is made up of two sides joined by cross members to form a box-like structure. The front part of the side sheet consists of a ½-inch plate welded to a ¼-inch plate. The front part of the side sheet is constructed of a heavy material for two reasons,—first, it is the leading edge of the bowl and is subjected to constant impact as it goes through the soil while the unit is in operation. Second, it must carry a welded box-section cross member. The lower front part of this side is made of a ¾-inch plate. The front part of this plate does the side cutting or routing as the scraper digs. This part of the plate is hard faced with an abrasion-resisting weld. This hard-surface coating can be replaced as wear occurs. In the former design, a high-manganese casting was bolted on at this point to take the abuse. (See Fig. 4).

Also attached to this plate is the heavily-reinforced box-section type of cutting edge. This cutting edge is subjected to all the wear and tear in the digging operation of the unit. The remainder of the side sheet is made of ¼-inch plate reinforced with horizontal and vertical box sections. The purpose of these reinforcements is to prevent these sides from bulging out due to the hydrostatic pressure of the load, and to form a rigid box section construction around the whole bowl. With the use of welding, it was possible to combine various-gauge plates in such a manner that the heavy plates could be placed in the position where they were needed. In this side, we used plates of three different thicknesses. These plates were located in such a manner that the highly-stressed portions of the side were made of heavy-gauge plate to take the load imposed on them. Where lesser loads occurred, thinner-gauge reinforcing material was used. This type of construction tends to eliminate the use of uniform-size plates throughout.

The two sides of the bowl are joined together by four box section-type cross member are welded to the front ½-inch side plate. Corner box-section-⅜-inch U-shaped plates welded together with a double-pass Vee weld. These U-shaped plates are beveled before welding. The ends of this front cross member are welded to the front ½-inch side plate. Corner box-section-type gussets are welded to this cross member and to the ½-inch side plate so that there is no concentration of stress on the weld.

To the middle of this cross member we have welded two ears which carry a cross tube and into this particular tube a link mechanism has been inserted. This link, which is connected to the bowl at this point, controls the lifting and lowering of the bowl and regulates the depth of the cut as well as the height of the spread.

The front member must also carry the upper track assembly. This track assembly consists of two U-shaped front beams, the lower parts of which are welded to the front cross member and the tops of which are welded to the top sheave housing. These members are welded to form an "A" so as to give a wide bearing at the bottom, thereby resulting in a rigid track assembly. The track assembly itself is of a box-section-type construction made of high tensile steel.

The rear lift link runs along this track. This rear lift link is connected to the movable floor which in turn carries the load of dirt. During the dumping cycle, this whole weight is borne by the track through the medium of the link. The rear part of this track assembly is rigidly welded to the top rear cross member of the bowl.

The top rear cross member and bottom cross member are U-shaped plates, welded to a common sheet to form the rear of the bowl. These box-section

cross members, being welded to the sides of the bowl, make a box-section construction which holds the bowl in perfect alignment.

To these cross members the rear axle assembly is welded. This rear axle assembly, which carries the wheels, must be thoroughly reinforced and of sturdy construction since it carries 55 per cent of the total weight of the scraper and pay load. (See Fig. 6).

The rear axle assembly consists of two ¾-inch side plates. A hole is burned out in these two plates to decrease their weight. These side plates are joined together by a common plate which in turn is welded to a rear cross member. This cross member has a bracket on each end which carries the wheel axles. These brackets were originally made of cast steel, but on the present unit they are burned out of 5-inch plate. This rear axle assembly is attached to the rear cross members of the bowl by means of box-section gussets on the top and bottom. A construction of this kind tends to prevent "stress raisers" which are caused by sharp corners or rapid changes in section. The rear lower cross member of the bowl also has welded to it five 1½-inch extensions which support the movable floor in its lowest position.

The fourth cross member is also the cutting blade bed and is a heavily-trussed structure permanently and rigidly welded to the bottom front part of the bowl. This was originally a cast steel member but it is now a triangular-shaped member made up of 1¼-inch and 1-inch plates. The welds on this cutting edge are made in several passes and a technique had to be developed in the welding procedure so that when this member was finished it was straight and not curved or twisted. We ran into considerable difficulty on this in some of our first attempts. Upon examination of Fig. 7, the welding procedure used in this construction can be readily seen since the passes are listed numerically.

The following method of calculation was used in arriving at the costs of the various welds employed in the construction of our scraper units.

Calculation

Labor	$1.00	per hour
Power	.02	per K.W.H.
Electrode	.095	per pound
Efficiency of machinery	50	Per Cent

¼″ Butt Weld

$$\text{Labor} = \frac{\text{Labor/Hour}}{\text{Welding Speed Ft./Hr.}} = \frac{1.00}{45} = .0222$$

$$\text{Power} = \frac{(\text{Amp.})\ (\text{Volts})\ (\text{Cost/KWH})}{(\text{Efficiency})\ (\text{Welding Speed Ft./Hr.})\ 1000} = \frac{200 \times 30 \times .02}{.50 \times 45 \times 1000} = .0053$$

$$\text{Electrode} = (\text{Amount of Electrode/Ft.})\ (\text{Cost/Lb.}) = .225 \times .095 = .0214$$

$$\text{Overhead} = 200\%\ \text{Labor} \qquad .0444$$

Total Cost per Foot of ¼″ Butt Weld .0933

The costs of the various welds, using the above calculations, are as given in Table I. This cost per foot of the various welds will be used in the calculation of the subsequent assemblies.

Fig. 4. (left). Side view of scoop during fabrication. Fig. 5. (right). Top view of scoop during fabrication.

Table I

Description of Weld	Cost Per Foot
¼" Butt	$0.0933
¼" Vee	0.223
¼" Lap	0.0641
¼" Fillet	0.1118
5/16" Butt	0.1105
5/16" Vee	0.2539
5/16" Lap	0.0838
5/16" Fillet	0.1238
⅜" Butt	0.1269
⅜" Vee	0.3298
⅜" Lap	0.1048
⅜" Fillet	0.1600

Table II—Welding Cost Analysis of the Bowl Assembly

	Old Construction		New Construction	
Description of Weld	Ft. Weld	Cost	Ft. Weld	Cost
¼" Butt	20′ — 2″	$ 1.89	21′ — 8″	$ 2.03
¼" Vee	14′ — 2″	3.16	25′ — 0″	5.57
¼" Lap	28′ — 4″	1.80	27′ — 6″	1.75
¼" Fillet	91′ — 8″	10.25	125′ — 0″	13.97
5/16" Butt	27′ — 3″	3.01	19′ — 5″	2.14
5/16" Vee	53′ — 7″	13.63	43′ — 9″	11.13
5/16" Lap	28′ — 4″	2.38	17′ — 8″	1.48
5/16" Fillet	192′ — 2″	23.75	182′ — 1″	22.51
⅜" Butt	8′ — 4″	1 06	6′ — 8″	.85
⅜" Vee	168′ — 6″	55.61	153′ — 4″	50.60
⅜" Lap	55′ — 10″	5.83	38′ — 6″	4.02
⅜" Fillet	192′ — 11″	30.79	184′ — 3″	29.42
Total Cost		$153.16		$145.47
TOTAL SAVING	=	$7.69		

Listed in Table III is a comparison of the plate used in both constructions, and the resulting savings in material weight and cost.

Cost of high tensile steel plate based on price of 3¼ cents per pound.

Cost of mild steel plate based on price of 2½ cents per pound.

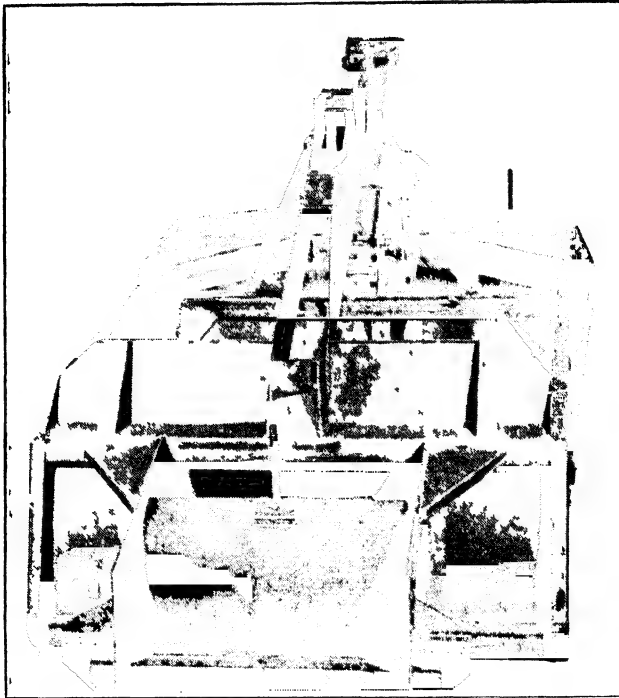



Fig. 6. Back view of scoop during fabrication.

Table III

Description	Old Construction Weight Lbs.	Old Construction Cost	New Construction Weight Lbs.	New Construction Cost
¼" mild steel	2015	$ 50.38	1904½	$ 47 61
5/16" mild steel	1230	30 75	773	19.32
⅜" mild steel	1362	34 05	951	23 77
½" & up mild steel	3641	91 03	3021½	75.54
¼" manten steel			210	6 82
5/16" manten steel			215	6 99
⅜" manten steel			302	9 81
	8248	$206 21	7377	$189 86

Total Saving in Weight = 871 lbs.
Total Saving in Cost = $16.35

By substitution of welded-plate construction in place of castings, considerable savings were realized over and above those previously mentioned. One of the most important savings was on the cutting edge bed plate as shown in Fig. 7.

Table IV

Casting Design

Item	Amount
Weight of casting = 1682 lbs.	
Cost @ .15 per Lb.	$252.30
Machine labor, 8 Hrs. @ $1.00 per Hr.	8.00
Overhead @ 200% of Labor	16.00
Total cost	$276.30

Welded Design

Item	Amount
Weight of steel plate = 1436 Lbs.	
Machine labor, 7½ Hrs. @ 1.00 per Hr.	$ 7.50
Machine burning, 5.6 Hrs. @ 1.00 per Hr.	5.65
Welding labor, 18.5 Hrs. @ 1.00 per Hr.	18.50
Grinding and cleaning labor, 4 Hrs. @ .60	2.40
Overhead @ 200% of labor	68.10
Power and cutting costs	4.09
Electrode cost, 84½ Lbs. @ .095	7.98
Hard facing electrode cost, 15 Lbs. @ $2.00	30.00
Steel plate cost @ 2½¢ per Lb.	35.90
Total cost	$180.12
Total savings in weight = 246 Lbs.	
Total savings in cost = $96.18	

A further saving resulted from elimination of the high manganese steel router casting. This router casting was replaced with an abrasion-resisting welded plate.

Table V

Side Router Casting

Item	Amount
Weight of casting = 110 Lbs.	
Cost of casting @ 22¢ per Lb.	$24.20
Grinding, 24 minutes @ .75 per Hr.	.30
Drilling, 1 Hour @ 1.00 per Hr.	1.00
Overhead @ 200% of labor	2.60
Total cost	$28.10

Welded Design

Item	Amount
Weight of steel plate = 90 Lbs.	
Machine burning, 1 Hour @ 1.00 per Hr.	$ 1.00
Welding labor, 1¼ Hrs. @ 1.00 per Hr.	1.25
Grinding, 20 minutes @ .60 per Hr.	.20
Overhead @ 200% of labor	4.90
Power and cutting cost	.70
Electrode cost, 8 Lbs. @ 2.00 per Lb.	16.00
Steel plate cost, 90 Lbs. @ 2½¢ per Lb.	2.25
Total cost	$26.30

There are two of these router castings used on a scraper unit therefore, the total saving in weight is 2 x 20 pounds, or 40 pounds total,—or a saving of $1.80 x 2 = $3.60.

The total savings on the whole bowl assembly as shown in Tables II, III, IV and V listed above, is $123.82, or 18 per cent.

Total saving in weight = 1.157 pounds.

Total saving in material and labor cost = $123.82 or 18%

Movable Floor, (See Fig. 8)—The movable floor is the second important

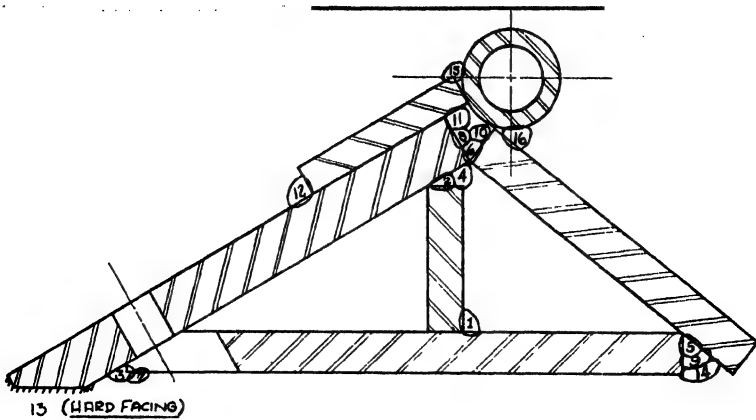



Fig. 7. Welding procedure on cutting edge.

part in the design of a scraper. This assembly forms the bottom support for the load. It is hinged in front on the front cutting edge of the bowl, and the back of it is supported on the extensions on the rear cross member of the bowl. The top sheet of this movable floor is designed in one piece of $\frac{5}{16}$-inch high-tensile plate where, previously, $\frac{3}{8}$-inch mild steel was used. Across the back of the floor are two horizontal box-section members, and the rear cross member rests on the extensions of the bowl.

Along the front part of this floor, longitudinal reinforcements are skip welded. These extend perpendicular to, and butt up against, the front rear cross member. The front part of these supports is welded to tubes, and these tubes form a hinge with the tubes which are welded on to the cross blade of the bowl. These reinforcing cross members taper from $2\frac{1}{2}$-inches in depth at the pivot end to 7 inches in depth at the point where they connect

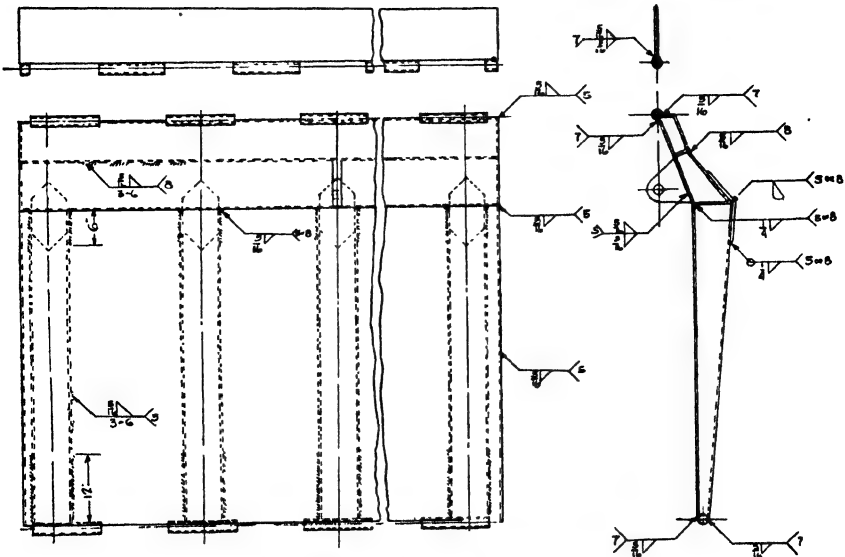



Fig. 8. Movable floor assembly.

with the rear cross member. This is to increase the section modulus in the same proportion to which these beams are loaded, and this can be readily accomplished with a welded plate design. Through the middle of the front rear cross member a $1\frac{1}{2}$-inch plate is welded. This is the point to which the lift link is attached, and all the pull is exerted at this point when the scraper load is discharged. Where the reinforcing members of the floor meet the front rear cross member, pointed butt straps are used. These butt straps are pointed at both ends in order to obtain more weld length instead of a concentration of weld.

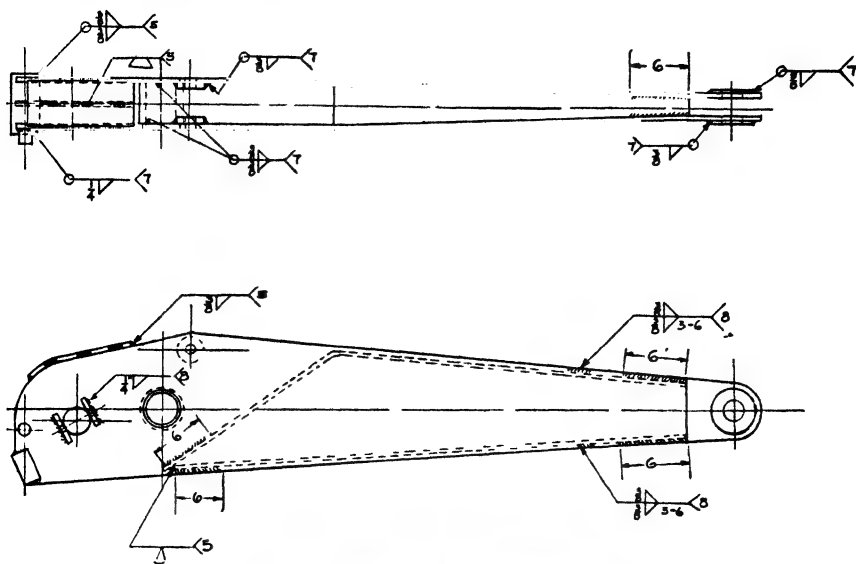



Fig. 9. Rear lift link assembly.

Welded to the rear cross member are tubes which tend to form a hinge connection with a flapper plate. The object of this flapper plate is to scrape the rear of the bowl clean after each operating cycle. The rear cross members are full-welded to the floor plate, but the reinforcing members are skip welded. This floor has not been changed materially from the previous design except that high tensile plate has been substituted for mild steel, resulting in a weight saving of 158 pounds.

Table VI—Movable Floor Assembly—Cost Comparison

Description of Weld	Old Construction Ft. Weld	Cost	New Construction Ft. Weld	Cost
1/4" Fillet	9′—5″	$ 1.05	9′—5″	$ 1.05
5/16" Vee	10′—0″	2.54	10′—0″	2.54
5/16" Lap	25′—0″	2.10	25′—0″	2.10
5/16" Fillet	50′—2″	6.26	71′—0″	8.79
3/8" Fillet	23′—4″	3.72		
Total cost		$15.67		$14.48
Total saving = $1.19				

Table VII—Comparison of Material Used

Description	Old Construction Weight, Lbs.	Old Construction Cost	New Construction Weight, Lbs.	New Construction Cost
¼" mild steel	27½	$ .69	27½	$ .69
5/16" mild steel	576	14.47	576	14.47
⅜" mild steel	965	24.12	245	6.12
½" and up mild steel	68	1.70	68	1.70
5/16" high tensile steel			562	18.26
Total cost	1636½	$40.98	1478½	$41.24

Total saving in weight = 158 Lbs.
Total loss in cost = 26¢
Total saving in movable floor as shown in Tables VI and VII
Total saving in weight = 158 Lbs.
Total saving in material and labor cost = $.93 or over 1%.

Rear Lift Link Assembly, (See Fig. 9)—The rear lift link assembly is the mechanical connection between the movable floor and the track assembly on the bowl. The movement of this link is actuated by a cable which is wrapped around the two sheaves in the upper part of the link. In view of the fact that this link is in tension at all times, its construction was simplified over that used in the previous design. It now consists of two side sheets separated by two plates, one welded straight along one end, and the other having a single bend and welded for most of the distance along the other end, causing this structure to be of a box-section construction. On the lower end of the link, where it connects with the movable floor, one washer is welded to each one of the side plates so as to secure enough bearing area for the connecting pin.

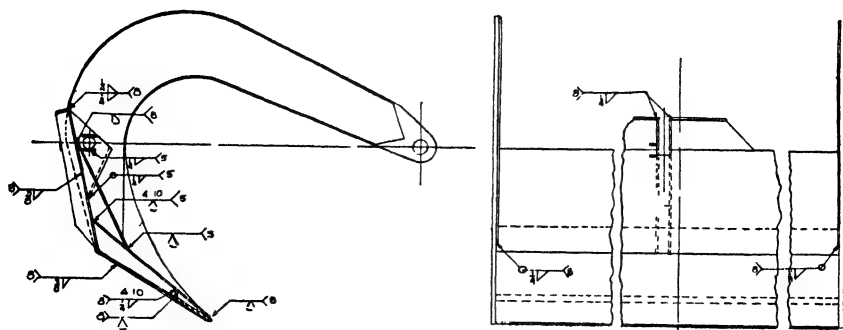



Fig. 10. Front apron assembly.

In the upper end of this rear lift link, a tube is welded, which serves as the hub for the bearings supporting the two rollers traveling up the track A 3 x 1½-inch bar is welded to the upper end of this link. This serves as a bumper or stop when the link has reached its maximum position. The upper part of the link also has a separator plate welded in so as to form individual housings for the two sheaves which are located at this point. The saving realized on this construction was through making the hub of tubing, welded to the side sheets, instead of using a casting. By making this a reinforced box section type of design, a material saving in weight was also realized.

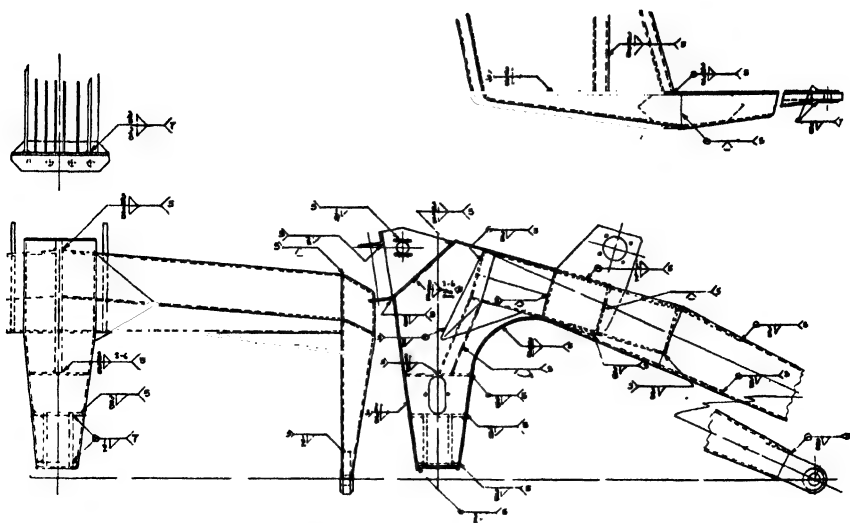



Fig. 11. Front lift frame assembly.

Table VIII—Rear Lift Link Assembly

Description of Weld	Old Construction Ft. Weld	Old Construction Cost	New Construction Ft. Weld	New Construction Cost
¼" Vee	1'— 6"	$ .33	1'— 0"	$ .22
¼" Fillet	2'—11"	.33	2'— 2"	.24
5/16" Vee	0'—10"	.21		
5/16" Lap	3'— 0"	.25		
5/16" Fillet	4'— 0"	.50		
⅜" Lap	2'— 6"	.26	4'— 2"	.43
⅜" Fillet	12'— 1"	1.93	10'—10"	1.72
Total cost		$3.81		$2.61
Total saving = $1.20				

Table IX—Plate Comparison

Description	Old Construction Weight, Lbs.	Old Construction Cost	New Construction Weight, Lbs.	New Construction Cost
¼" mild steel	15	$ .38	12½	$ .31
5/16" mild steel	45	1.13		
⅜" mild steel	225	5.63	199	4.97
½" and up mild steel	12	.30	24	.60
Total cost	297	$7.44	235½	$5.88
Total saving in weight = 61½ Lbs.				
Total saving in cost = $1.56.				

The hub was changed from a cast to a welded tube design. The comparisons in Table X show the savings effected.

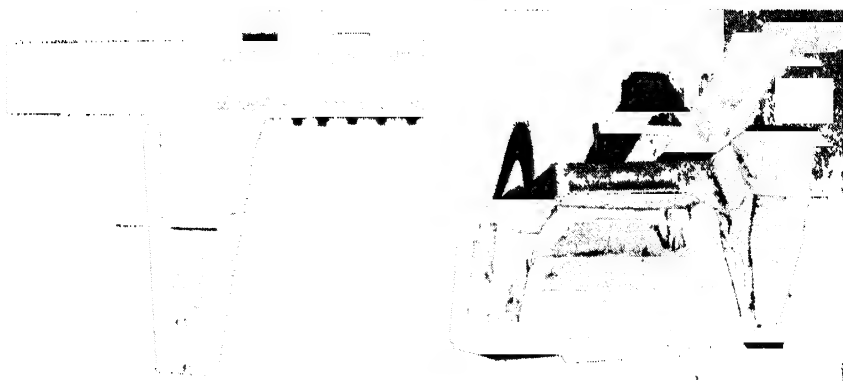



Fig. 12, (left). Cut-away view of front gooseneck. Fig. 13, (right). Front view of lift frame during fabrication.

Table X—Cast Design

Weight of casting = 12 Lbs.	
Cost of casting, 12 Lbs. @ .18 per Lb.	$2.16
Machine labor ¾ Hr. @ 1.00 per Hr.	.75
Overhead @ 200% of labor	1.50
Total cost	$4.41

Welded Design

Weight of tubing = 9 Lbs.	
Machine labor, ½ Hr. @ 1.00 per Hr.	$ .50
Welding labor, 9 minutes @ 1.00 per Hr.	.15
Grinding and cleaning @ .60 per Hr.	.15
Overhead @ 200% of labor	1.60
Power and electrode cost	.15
Tube cost, 9 Lbs. @ 8¢ per Lb.	.72
Total cost	$3.27

Savings in weight = 3 Lbs.
Savings in cost = $1.14.
Total savings on rear lift link assembly, as shown in Tables VIII, IX and X are as follows:
Total saving in weight = 64½ Lbs.
Total saving in material and labor cost = $3.90 or 24.8%.

Front Apron Assembly, (See Fig. 10)—The main function of the front apron assembly is to retain the load during the transportation cycle. This assembly is made up of two reinforced side arms which are inter-connected in front by a reinforced plate, and the back portions of these side arms pivot about a trunnion pin welded into the sides of the bowl. The lower tip of the front sheet is outwardly reinforced by an "L" section made of ⅜-inch plate and welded to form a box section. This is the part of the front apron which is subjected to the most abuse.

The remainder of this apron is constructed in such a manner so as to form horizontal box sections which tend to make the apron torsionally strong so that it will not distort when carrying its proportional share of the load. Skip welding was employed wherever possible in this new design so as to effect a saving in labor cost. Another saving was made by constructing the inside lower cross plate out of thinner-gauge high-tensile material.

In the previous design, a hardened-steel cutting bit was bolted along the lower tip of the front apron. In our present design, we use a little heavier gauge material in our "L"-shaped box section, and we weld a wearing tip on it with abrasion-resisting weld. A saving of material resulted in the elimination of this hardened-steel cutting bit as well as the labor connected with the drilling of holes and attaching of this bit. A bracket, which carries the operating sheave, is welded in the center of the front apron.

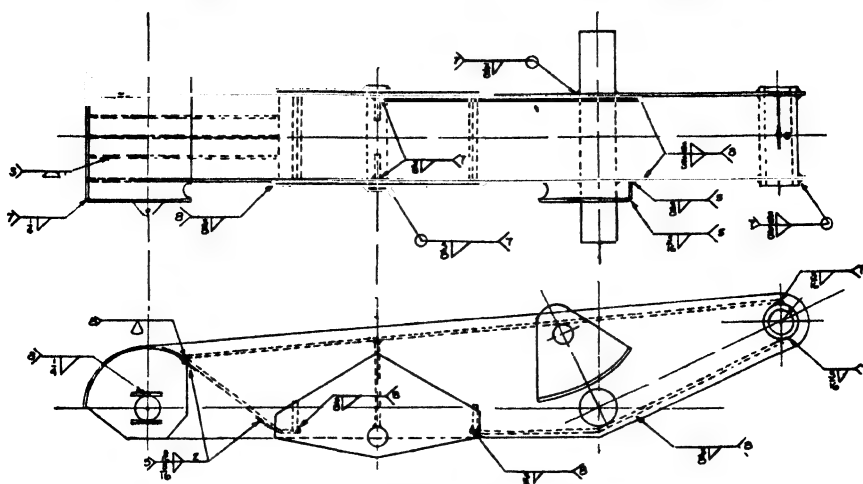



Fig. 14. Front lift arm assembly.

Table XI—Front Apron Assembly

Description	Old Construction Ft. Weld	Old Construction Cost	New Construction Ft. Weld	New Construction Cost
1/4" Vee	29'— 2"	$ 6.51	30'— 0"	$ 6.69
1/4" Lap	15'— 0"	.96	12'— 6"	.80
1/4" Fillet	58'— 5"	6.53	51'— 3"	5.73
5/16" Vee	11'— 3"	2.86		
5/16" Lap	13'— 4"	1.12		
5/16" Fillet	10'— 0"	1.24		
3/8" Vee	17'—11"	5.91	20'— 0"	6.60
3/8" Lap	9'— 2"	.96	10'— 0"	1.05
3/8" Fillet	18'— 4"	2.93	10'— 6"	1.68
Total cost		$29.02		$22.55

Total Saving=$6.47

Table XII—Plate Comparison

Description	Old Construction Weight, Lbs.	Old Construction Cost	New Construction Weight, Lbs.	New Construction Cost
1/4" mild steel	140	$ 3.50	187	$ 4.67
5/16" mild steel	360	9.00		
3/8" mild steel	240	6.00	181	4.52
1/2" and up mild steel	1600	40.00	1640	41.00
1/4" high tensile steel			230	7.47
Total cost	2340	$58.50	2238	$57.66

Total saving in weight = 102 Lbs.
Total saving in cost = 84¢

A saving was also brought about by eliminating the high carbon cutting edge. A comparison between our old and new designs is given in Table XIII.

Table XIII

Weight of high carbon edge = 127.5 Lbs.	
Cost high carbon edge and bolts	$25.50
Machining of holes, ¾ Hr. @ 1.00 per Hr.	.75
Assemble blade, 40 minutes @ .75 per Hr.	.50
Overhead @ 200% of Labor	2.50
Total cost	$29.25

Present Design

Welding labor @ 1.00 per Hr.	$ 3.57
Overhead @ 200% of Labor	7.14
Electrode Cost, 8 lbs. @ 2.00 per Lb.	16.00
Power Cost	.25
Total cost	$26.96

Total saving = $2.29
Total savings on front apron assembly, as shown in Tables XI, XII and XIII are as follows:
Total saving in weight = 229½ Lbs.
Total saving in material and labor cost = $9.60, or 8.2%.

Front Lift Frame Assembly, (See Fig. 11)—Another one of the highly stressed parts in the scraper is the front lift frame assembly. This assembly must be able to transmit all of the tractor drawbar to the cutting edge of the scraper as well as carry 45 per cent of the weight of the scraper plus the weight of the bowl. The front lift frame must be strong and rigid torsionally. Consequently, this member is made up wholly of reinforced box section, and the majority of the plates used in its construction are high-tensile steel.

The two side arms of this lift frame are made up of U-section type plates welded to a second plate to form an enclosed rectangular box section. These arms taper in both dimensions, increasing in section so as to be able to have a section modulus big enough to carry the load imposed upon them. These two side arms have additional plate reinforcements welded inside at the points of maximum stress. Full corner welds are used along the length of these side arms. During fabrication, these side arms are welded in pairs. They are placed in a jig which holds the two ends together. Any tendency for one arm to warp during welding is prevented by the other and, consequently, both arms are straight after welding.

A bearing is attached to the lower end of the side arms. This bearing, in the new design, is burned out of 1½-inch plate. One ⅝-inch washer is welded on each side of this bearing in order to secure the calculated bearing area. In this manner, a strong bearing is secured, which can be very easily manufactured from relatively inexpensive plate instead of expensive castings. A pin going through these bearings connects them to the sides of the bowl, and it is about these pins that the bowl pivots in order to secure the depth of cut and the height of spread.

The front ends of these side members are welded to the front cross member. This front cross member is made in two halves which weld to a 1¼-inch plate at the center, and the outside ends of these cross members are securely welded with a double pass weld to the side arms, (See Fig. 12). These front members are made up of U-section plates welded together. These plates are chamfered for a heavy Vee weld. The front cross member

also tapers, being largest where the maximum stress occurs. Equally spaced at the center of this cross member are two ears made up of ⅝-inch plate securely welded to the cross members. These plates carry cast iron trunnion bearings in which the front lift arm, that carries the bowl, pivots

A large box-section type of gusset reinforces the corner where the side arms and the front cross section members are joined. This corner gusset helps stiffen the front lift frame torsionally at this point as well as to eliminate a stress concentration at the corner.

Connected to the center of the lift frame and extending downward is the so called "goose-neck," (See Fig 13). Down through the center of the gooseneck is a 1¼-inch plate This plate extends down just far enough to allow clearance for the swivel yoke The other part extends back far enough so as to connect with the two halves of the front cross member. This front gooseneck is also of a box-section construction, the sides of which are welded to the front cross member The front and rear sheets of the gooseneck pass up over the top and bottom of the front cross member, forming a butt connection Slots are cut in these sheets so as to plug weld them to the 1¼ inch center rib

The assembly of this gooseneck is accomplished in the following manner. First, the two halves of the cross members are welded to the 1¼-inch plate, then the front and rear sheets of the gooseneck are welded in turn to the 1¼-inch plate and to the front cross members, (See Fig 12) Next, two plates are welded down the center of the 1¼-inch plate tying the cross members to the center rib and preventing a corner concentration of weld. In the bottom part of the gooseneck is a bearing block which consists of a tube welded to two plates This welding is done before the assembly is put into the lower part of the gooseneck, and then the whole assembly is welded to the front and rear sheets After this is accomplished, then the two side sheets of the gooseneck are welded to the front and rear sheet as well as to the front cross member The welds along the gooseneck are corner welds

⁷⁄₁₆ x 1½-inch slots are punched in these side sheets for plug welds which tie the side plate to the inside reinforcing plate A corner box-section type of gusset ties this side sheet to the front cross member, reinforcing the corner In the upper part of this gooseneck, spacer plates are welded to carry the various sheaves which control the operation of the scraper A swivel clevis is inserted in the bottom part of this gooseneck Originally this swivel was made of an alloy steel casting In the present design, it is constructed of 4½-inch burned plate which has two 2-inch ears welded on to it to form this clevis A saving was brought about in this change The majority of the plates in the front lift frame are now made of high tensile steel, resulting in a weight saving

· Table XIV—Front Lift Frame Assembly

Description	Old Construction Ft. Weld	Old Construction Cost	New Construction Ft. Weld	New Construction Cost
¼" Vee	13'— 9"	$ 3.07	10'- - 0"	$ 2.23
¼" Fillet	17'—11"	2.00	15'—0"	1.68
⅜" Butt weld	39'— 7"	5.04	35'- - 2"	4.47
⅜" Vee	72'—11"	24.06	57'—1"	22.59
⅜" Lap	78'— 0"	8.17	47'—8"	4.98
⅜" Fillet	156'— 0"	24.96	127'—4"	20.22
Total cost		$67.30		$56.17

Total saving = $11.13

Table XV—Plate Construction

Description	Old Construction Weight, Lbs.	Old Construction Cost	New Construction Weight, Lbs.	New Construction Cost
1/4" mild steel	138	$3.45	90 1/2	$2.26
3/8" mild steel	195	4.88	41 1/2	1.04
1/2" and up mild steel	2282	57.05	986	24.70
3/8" manten steel	1427	46.58	2466	80.15
	4042	$111.96	3584	$108.15

Total saving in weight = 458 Lbs.
Total saving = $3.81
Total savings on front lift frame assembly, as shown in Tables XIV and XV are as follows:
Total saving in weight = 458 Lbs.
Total saving in material and labor cost = $14.94, or 8.3%.

Front Lift Arm (See Fig. 14)—Another assembly of the scraper which is also highly stressed is the front lift arm. This lift arm raises and lowers the bowl of the scraper by means of a link. It pivots in two bearings which are bolted to the two brackets welded on the front lift frame. This front lift arm has been designed so that a mechanical advantage is secured in favor of the cables which operate the sheaves located in the front end of the arms. The amount of movement of the rear part of the lift link is sufficient to give us the required cut and spread on the cutting edge of the scraper.

This arm is made up of four plates forming a box section. At the fulcrum point, a 3 1/2-inch diameter bar is welded and this serves as the trunnion of the lift arm. A tube is welded in the back end. A link which connects to the bowl is inserted into this tube. This is the mechanical link connection between this lift arm and the bowl. The front part of this lift arm carries the operating sheaves and it consists of numerous spacer plates welded so as to form individual sheave housings. A two inch cross tube is welded in the lower center section of this lift frame. This cross shaft is welded on the ends to gusset plates which in turn are welded to the side sheets of the lift arm. Corner gussets also tie the inside of this pin to the inside side sheets of the lift arm. The function of this pin is to serve as an anchor for the lift arm in carrying position, (See Fig. 15).

An automatic patented hook arrangement is attached to the front lift frame and hooks around this pin while the scraper is in transportation. The object of this is to take all of the load off of the cable. This hook is burned out of 2-inch plate and it pivots about a pin which in turn is anchored to the top of the lift frame. This hook is of the self-applying type and automatically releases as the hook is tripped past center.

Table XVI—Front Lift Arm

Description	Old Construction Ft. Weld	Old Construction Cost	New Construction Ft. Weld	New Construction Cost
1/4" Vee	4'— 0"	$ .89	3'— 4"	$ .74
1/4" Fillet	14'— 2"	1.58	11'— 8"	1.30
5/16" Lap	2'— 4"	.20	2'— 6"	.21
5/16" Fillet	7'— 11"	.98	5'— 0"	.62
3/8" Vee	6'— 8"	2.20	3'— 4"	1.10
3/8" Lap	21'— 8"	2.26	15'— 0"	1.57
3/8" Fillet	26'— 4"	4.20	21'— 2"	3.38
Total cost		$12.31		$8.92

Total saving = $3.39

Fig. 15. Front lift arm with self-applied hook.

Table XVII—Material Saving

Description	Old Construction Weight, Lbs.	Old Construction Cost	New Construction Weight, Lbs.	New Construction Cost
1/4" mild steel	76	$1.97	60½	$1.51
5/16" mild steel	65	1.63	51	1.28
3/8" mild steel	315	7.88	8	.20
1/2" and up mild steel	18	.45	13	.32
5/16" high tensile steel			200	6.50
	474	$11.93	332½	$9.81

Total saving in weight = 141½ Lbs.
Total saving in cost = $2 12
Total savings on front lift arm assembly, as shown in Tables XVI and XVII are as follows:
Total saving in weight = 141½ Lbs.
Total saving in material and labor cost = $5.51, or 22.7%.

Wheel Assembly (See Fig. 16)—Originally, the rear wheel was purchased from a local wheel company, and was bolted to a cast hub. In view of the fact that this wheel took a 15-inch rim, the cost was high since there was no large production on this size. The machining of the hub was also expensive due to its size. These factors caused us to consider designing an all fabricated wheel, (See Fig. 17). The net result was that we decided to purchase from the wheel company the largest production rim which they manufactured. We then cut it in half and spread it to the required width by welding in a spacer plate rolled to the correct diameter. This rim was cut on a lathe and the tool used was a "V"-shaped tool which allowed us to make a Vee-type weld.

The hub was next hot formed out of 1-inch plate and the same was welded with a triple-pass weld. This hub was then rough-machined on the outside. Next the outside disc plate was machine-burned and dished. This plate is now welded to the hub. The back disc plate is a straight ½-inch plate which is welded to a flanged ring and both these plates are in turn welded to the hub. This flanged plate is later machined to carry the brake

frame assembly. This machining is all done in one setting, and the cost of it is considerably less than on the previous design.

These two disc plates are in turn welded to six equally-spaced reinforcing gussets. The rim, which has been widened, is slipped over these disc plates to the proper location and welded around both of the outside diameters of these disc plates. After this wheel is fully welded it is finish-machined on a vertical boring bar. This machining now is relatively simple and a considerable saving has been achieved. Our production has been such that we can set up a motor driven welding fixture, and we can now make these wheels for a fraction of the cost of the wheels previously used.

Table XVIII—Wheel Assembly

Old Construction	
Weight of cast hub	222 lbs.
Weight of wheel	216 lbs.
Total weight	438 lbs.
Cost of wheel and bolts	$21.40
Cost of hub @ 15c per Lb.	33.30
Machining labor for hub @ 1.00 per Hr.	7.62
Overhead @ 200% of Labor	15.24
Total cost	$77.56
New Welded Construction	
Weight of hub	152 lbs.
Weight of rim and rings	142 lbs.
Weight of side plate	128 lbs.
Total weight	422 lbs.
Cost rough machining hub @ 1.00 per Hr.	$ .65
Machine burn, labor @ 1.00 per Hr.	.26
Forging labor @ .75 per Hr.	.75
Welding labor @ 1.00 per Hr.	2.25
Grinding and Cleaning @ .60 per Hr.	.60
Final machining of wheel	3.76
Overhead @ 200% of labor	18.54
Power and cutting cost	.75
Electrode cost, 18 lbs. @ .095 per Lb.	1.71
Steel plate, 128 lbs. @ 2½¢ per Lb.	3.20
Cost of rim	15.60
Total cost	$48.07

Saving in weight per wheel equals 16 pounds, or 32 pounds total for two.
Saving in cost per wheel equals $29.49, or $58.98 total.

Push Bumper (See Fig. 18)—Attached to the rear part of the bowl of the scraper is a spring cushion push bumper. This consists of a 1-inch plate forged into the shape of a mushroom top. At the center of this shoe a 5-inch diameter plate is welded. This plate butts up against the spring. The spring, in turn, is partially enclosed in a tube-type of carrier which is closed at the rear. A bolt welded to this mushroom passes through the center of the spring with a nut on the outside of the carrier. This is to prevent the top from falling off. This tube in turn is welded to two plates, one at the front and one at the rear. These two rectangular plates in turn are welded to a box-section type of frame. This type of frame bolts on to the rear of the scraper.

This push bumper is a very necessary item on these scoops. As stated before, speed is of prime importance in this unit. Usually a contractor buys

several of these units at one time. He figures out his cycle of operation in such a manner that when one unit is loading, the other unit pushes on the push bumper of this unit, thereby increasing its loading speed. These push bumpers are also invaluable in helping to push the unit in case it is stuck in very unusual or soft terrain.

A progressive contractor also maintains a push tractor on the cut, the function of which is to "push-load" the scraper units so as to speed up the loading cycle.

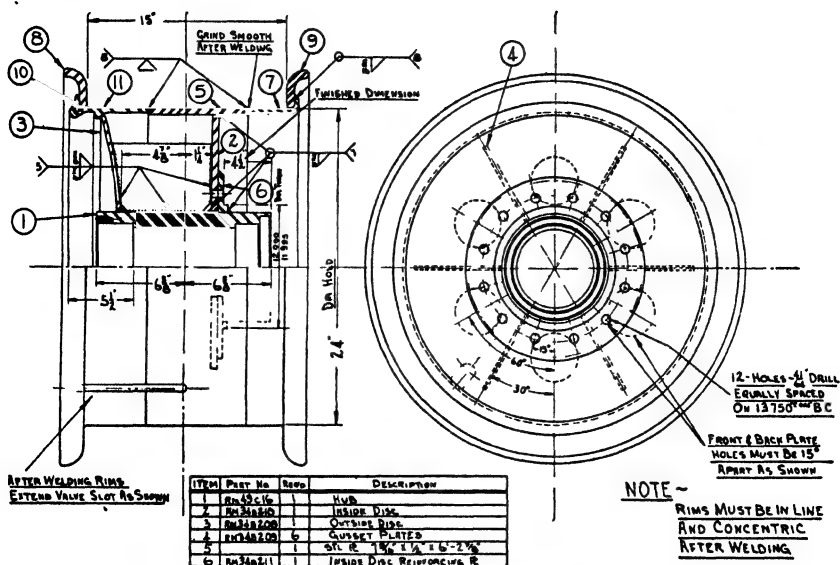



Fig. 18. Wheel assembly.

There is no listing of comparative savings on the above mentioned push bumper since this bumper is identical with the one used on the previous-model scraper.

In addition to the savings enumerated in the foregoing pages, numerous other savings were accomplished in the construction of some of the small details. For the purpose of simplicity and so as not to make this paper too involved with small details, these savings will be combined under the "Miscellaneous Group" in the summary of savings listed in Table XIX.

Table XIX—Summary of Savings

Description	Weight, Lbs.	Material & Labor
1. Bowl assembly	1157	$123.82
2. Movable floor assembly	158	.93
3. Rear lift link assembly	64½	3.90
4. Front apron assembly	229½	9.60
5. Front lift frame assembly	458	14.94
6. Front lift arm assembly	141½	5.51
7. Wheel assembly	32	58.98
8. Miscellaneous	65	14.16
	2305½	$231.84

If we manufacture 100 of these units, we will realize a saving of $231.84 x100, or $23,184, due to the redesigned welded construction. **This represents a total saving on material and labor of approximately 15 per cent.**

The savings set forth in the previous pages cover those realized by the manufacturer. There are, however, substantial savings which the operator or contractor can realize by having a unit which will travel twice as fast, carrying the same amount of load each trip as a crawler-tractor drawn unit. As a result of this speed, the contractor is able to move twice as much dirt in the same period of time as would be possible with the former construction. In this present emergency, where there is a shortage of steel and rubber, we have found it possible to increase the output for the contractor. In other words, the contractors have found that one unit of our newly-designed type will do the work of two of the previous units, and therefore a material saving in steel and rubber is effected. In the present rush of constructing air ports, munition plants and army camps, this particular unit is proving itself to be extremely valuable.

Tables XX and XXI give comparative cost figures for units operating under similar conditions.

Table XX

Estimated output in cubic yards of "pay dirt" per hour with C-15 cable scraper drawn by Crawler Tractor, loaded on level ground with 100 H.P. Push Tractor of the Crawler Type (our former design).

Haul One Way in Feet	Pay Dirt Per Hour
300	190 Cu. Yds.
400	170 "
500	155 "
600	125 "
800	110 "
1000	100 "
1500	78 "

Estimated Loading and Haul Cost for C-15 Cable Scraper

Daily Cost — 10 Hours (scraper-tractor unit)

Item	Cost
Operator @ 1.25 per Hr.	$12.50
Fuel, 55 gals. @ 8¢	4.40
Oil, Grease, Tires, etc.	2.00
Depreciation (10,000 Hours)	11.90
Interest and Insurance	1.75
Repairs, etc.	2.00
Total Cost (10 Hours)	$34.55

Daily Cost — 10 hours (push tractor)

Item	Cost
Operator @ 1.25 per Hr.	$12.50
Fuel, 40 gals. @ 8¢	3.20
Oil, grease, tires, etc.	1.20
Depreciation (10,000 Hours)	6.50
Interest and insurance	1.00
Repair, etc.	1.25
Total Cost (10 Hours)	$25.65

Assuming a 1,000 ft. haul, one push tractor will be able to handle three tractor-scraper units.

Then, total daily cost = 3 x 34.55 = 103.65
Push tractor = 1 x 25.65 = 25.65

Total daily cost (10 Hours) $129.30

129.30 = 10 Hours = $12.93 Cost per hour with pusher
At 1,000 ft. haul = 3 x 100 = 300 Yards hauled per hour with three units.
12.93/300 = .0431¢ = Cost/Yard on 1,000 ft. haul.

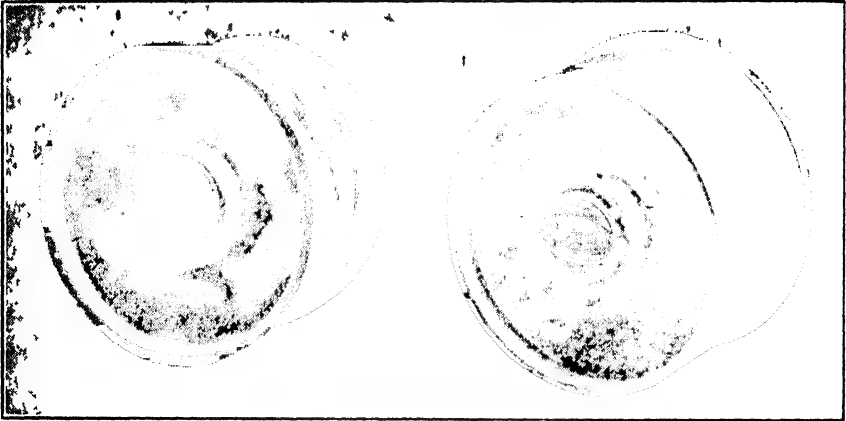



Fig. 17. Fabricated wheel assembly.

Table XXI

Estimated output in cubic yards of "pay dirt" per hour with CT-15 Hi-Speed Scoop drawn by a rubber tired tractor, loaded on level ground with 100 horsepower Push Tractor of the Crawler Type (new design).

Haul One Way in Feet	Pay Dirt Per Hour
600	240 Cu. Yds.
800	230 "
1000	216 "
1500	180 "
2000	144 "
2500	128 "
3000	110 "
4000	86 "

Estimated Loading and Haul Cost for CT-15 High-Speed Scoop

Daily cost — 10 Hours (high-speed unit)

Operator @ 1.25 per Hour	$12.50
Fuel, 40 gals. @ 8¢	3.20
Oil, Grease, Tires, etc.	2.50
Depreciation (10,000 Hours)	15.00
Interest and Insurance	2.25
Repairs, etc.	1.00
Total cost (10 Hours)	$36.45

Daily cost — 10 Hours (push tractor) $25.65

Assuming a 1,000 ft. haul, one push tractor will be able to handle three high-speed units.

Then, total daily cost = 3 x 36.45 = 109.35
Push tractor = 1 x 25.65 = 25.65

Total daily cost (10 Hours) $135.00

135.00 = 10 Hours = $13.50 Cost per hour with pusher
At 1,000 ft haul = 3 x 216 = 648 Yards hauled per hour with three units.
13.50/648 — .0208¢ — Cost/Yard on 1,000 ft. haul.
Therefore, .0431 — .0208 = .0223¢ saved on each yard of dirt hauled.

The contractor, saving .0223 cent on every yard of dirt hauled, could, on a project involving 1,000,000 yards, save in the neighborhood of $22,300, since he could complete the job in less than half the time required by our former type of scraper.

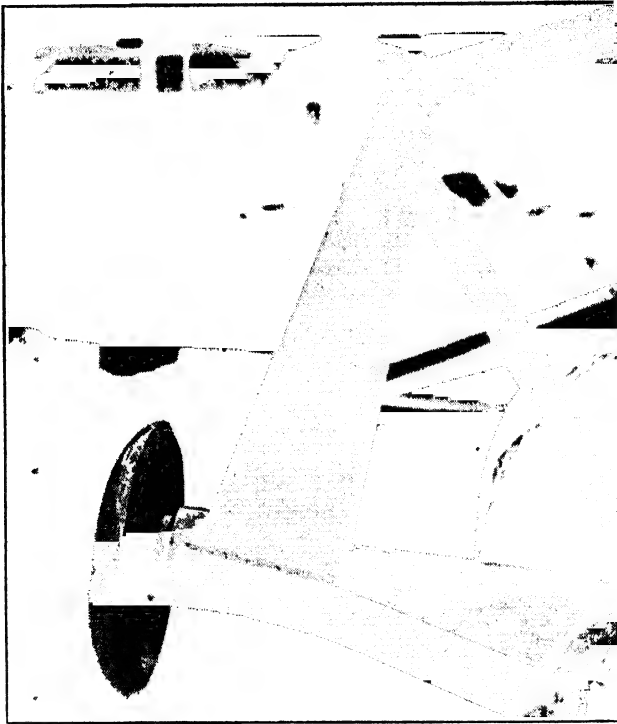



Fig. 18. Push bumper.

In designing this scoop we also kept the matter of service in mind. All of the parts of this unit are of welded construction, and if failure results they can be repaired by welding with a minimum amount of time lost. At the present time, practically every progressive contractor maintains welding equipment on the job to take care of emergency repairs. With the present national defense program, deliveries on steel castings are very uncertain and at best may take several months. Our new scoop, which has eliminated all but six pounds of steel castings, can be serviced very readily and economically by the contractor in the field through the use of arc welding. This new design with only six pounds of steel castings is far superior from the service angle to the former design which used approximately 3,261 pounds of steel castings. It can be seen from this that delays due to breakdowns, which cost the contractor on an average of $216 per day per unit, are materially reduced with our new all-welded design. In addition, hard-surfaced parts which have become worn can be very readily reconditioned in the field by the contractor without delaying the job.

The new scoop is also ideally suited for maintenance work because with the rubber-tired tractor it can be operated on present highways. It has been the consensus of opinion among the members of the road machinery industry that when the present emergency has passed, there will be a large highway-building program. However, for the duration, the high-speed scoop is being used extensively to maintain existing highways in good condition.

Chapter X—15-Ton Low-Bed Trailer Frame

By JAMES BLACK,

Vice President in Charge of Engineering,
Trailer Company of America, Oakley, Cincinnati, Ohio

James Black

Subject Matter: The joints in the steel sections are prepared by flame cutting. The assembly is placed in jigs and welded upside down. Considerable savings are made in both cost and in use of available space.

In 1936 with the advent of 15-inch base diameter low-speed high-capacity tires, we produced a trailer for transportation of machinery and the like and termed same "15-ton Drag", (See Fig 1).

The construction was riveted as was our standard practice. From time to time, these units were built in what was then termed large quantities so that a reasonable average of labor and machine hours was established.

The unit was successful in its operation and performance, and divided itself into 3 models, 15-ton, 20-ton and 25-ton units and became the standard of comparison.

Constant demands of late for increased production on this and similar vehicles brought about an overloaded condition to our machinery, and our assembly lines were filled beyond capacity.

We examined this frame to see what could be saved by welding, in order to reduce machining time, frame assembly time, and final assembly together with space hours.

A completely welded structure was then designed. Each joint was analyzed and changes in the design will now be described in detail. Every part was con-

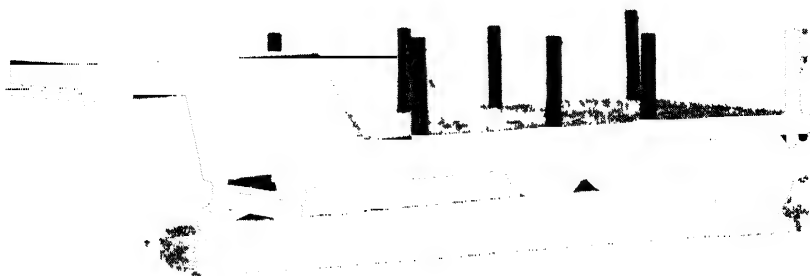



Fig. 1. Original unit.

sidered as a separate unit to see that a minimum of machining and a maximum of tolerance was allowed, and which would bring out a rugged and accurate product.

A photo of this unit is shown, (See Fig. 2), and each joint that is analyzed is marked. Sketches show it as it was and as redesigned to weld. As a plan, each new joint had to theoretically develop in excess the previous strength.

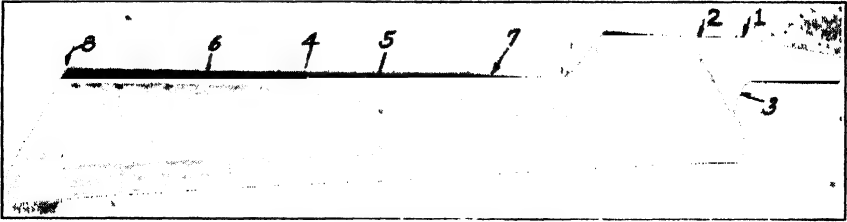



Fig. 2. Joints described in text.

There is an absolute similarity of parts in the original front corner joint. (See Fig. 3), and its counterpart in welding. Included in the assembly of the side rail, two cross members, two intermediate members, and fifth wheel plate, were 104 holes to be punched, and 52 rivets to be driven.

The design was changed to have four cross members of lighter weight in place of the 2 plus intermediates. Each cross member now carries but half the load that was formerly imposed. They are made of lighter material and formed from sheet rather than structural steel.

This allowed punch press notching rather than coping or burning out to shape.

The length is now controlled by rapid shearing rather than sawing and all four cross members are alike.

The cross members are butted into the frame and welded in completely around the top, and web one side only and lower flange is welded to the fifth wheel plate as is the fifth wheel plate to the cross members 3-inch skip 3.

Positioning for all welding and amount will be discussed later.

The original drop joint, (See Fig. 4), of the rails was assembled of 9 parts

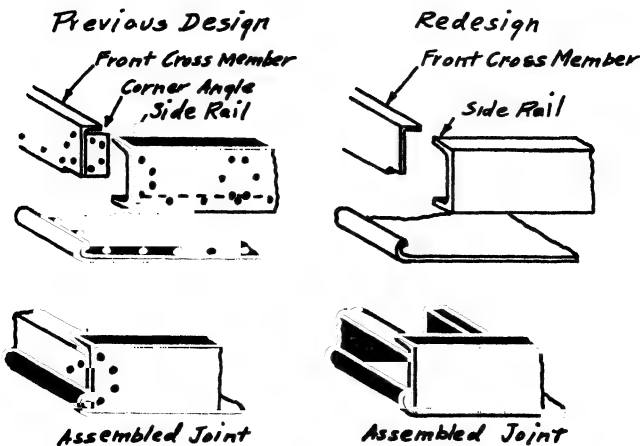



Fig. 3. Previous design and redesign of front corner joint.

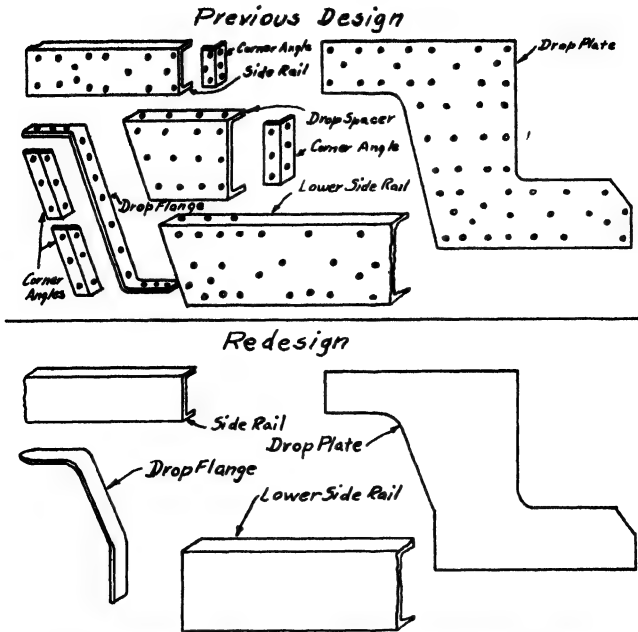



Fig. 4. Previous design and redesign of drop joint on rails.

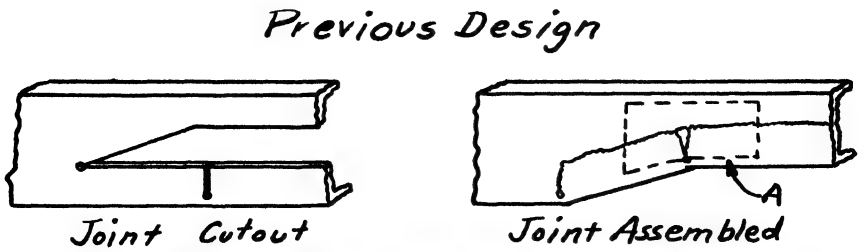



Fig. 5. (left). Joint cut-away. Fig. 6. (right). Joint assembled in previous design.

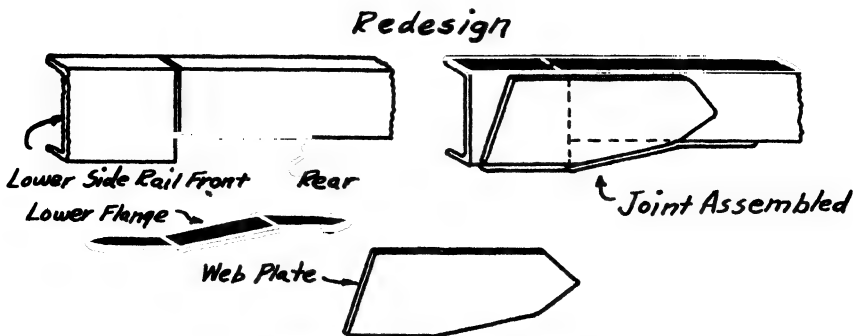



Fig. 7. Redesign of rear joint.

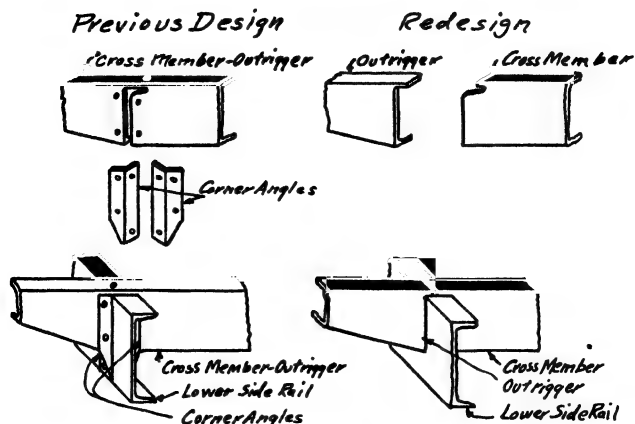



Fig. 8. Previous design and redesign of cross member and outrigger.

on each side as shown and had therein 82 rivets per rail which meant, per unit, 328 matching holes and 164 rivets. In addition, each part had to be accurate to insure alignment of rivets.

The new drop is made of five parts, which are in general, cut off within reason to size and jig welded to an accuracy and squareness which exceeds the riveted drop.

The rear joint was flame cut to pattern as shown on Fig. 5, folded into position as shown on Fig. 6 and welded. A reinforcing plate was inserted at point "A" which acted as a filler for the open triangle and reinforced the rail at the change of section as per calculations. The warping from flame cutting was not uniform and the rails required straightening. The new joint, (See Fig. 7), was developed to overcome this warp and reduce the work on the burner.

Here we change from smaller number to simpler parts and use four parts

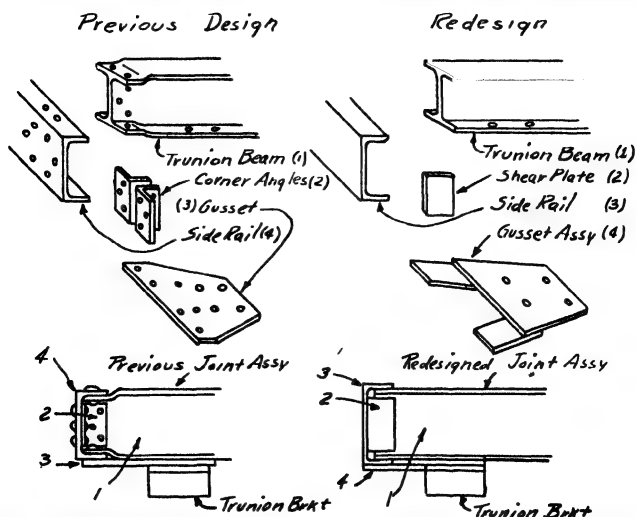



Fig. 9. Previous design and redesign of trunnion cross member joint.

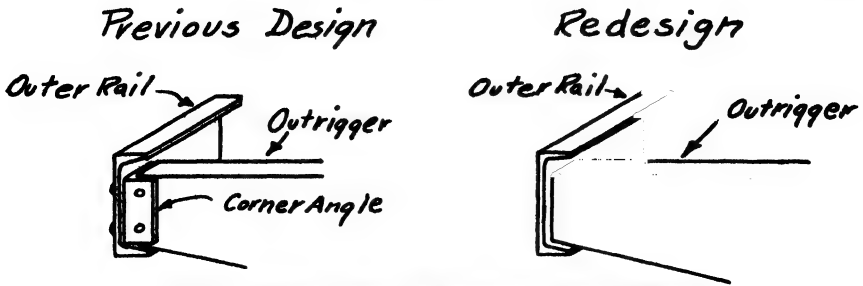



Fig. 10. Previous design and redesign of outer rail joint.

at this joint in place of two. Welded in a jig, this straight-cut material, excepting the shaped reinforcement plate which is sheared from drop plate scrap, remains uniform after welding, decreases time consumed in making the joint and allows further jigging because of uniformity of results.

The original design, (See left, Fig. 8), included cross member outrigger units to allow a through-tension strap across the upper flange of the frame as shown. This did not allow rapid assembly through jigging as the members had to be threaded on the main rail.

In redesign calculations, it was found that if the cross member and outrigger were separated, a joint stronger, (See right, Fig. 8), than the original strap could be had across the upper flange of the rail. The speed of assembly in jigs was the main factor in separation of the combination.

The original design of the trunnion cross member joint and carrier, (See left, Fig. 9), was made by "crocking" the I-beam carrier and riveting into frame with corner angles and gussets. It required torching, welding and fitting of the parts.

The assembly required 72 holes and 36 rivets in addition to the forming and welding of the member which also had to tightly fit in the side rail.

In the redesign to weld, (See right, Fig. 9), a cross beam was selected which would insert and fit tightly into the side rail. It was made short to allow the cross beam to be turned into position in the welding fixture. The joint to the side rail is attached with shear plates and the flanges welded to side rail flanges. The gusset and straps are divided to keep the same trunnion height

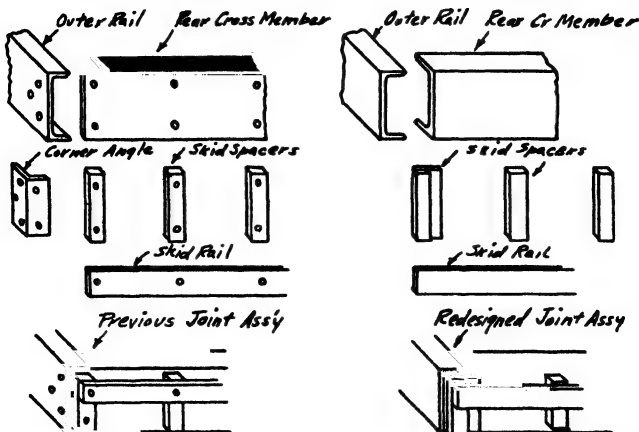



Fig. 11. Previous and redesigned assembly of rear corner joint.

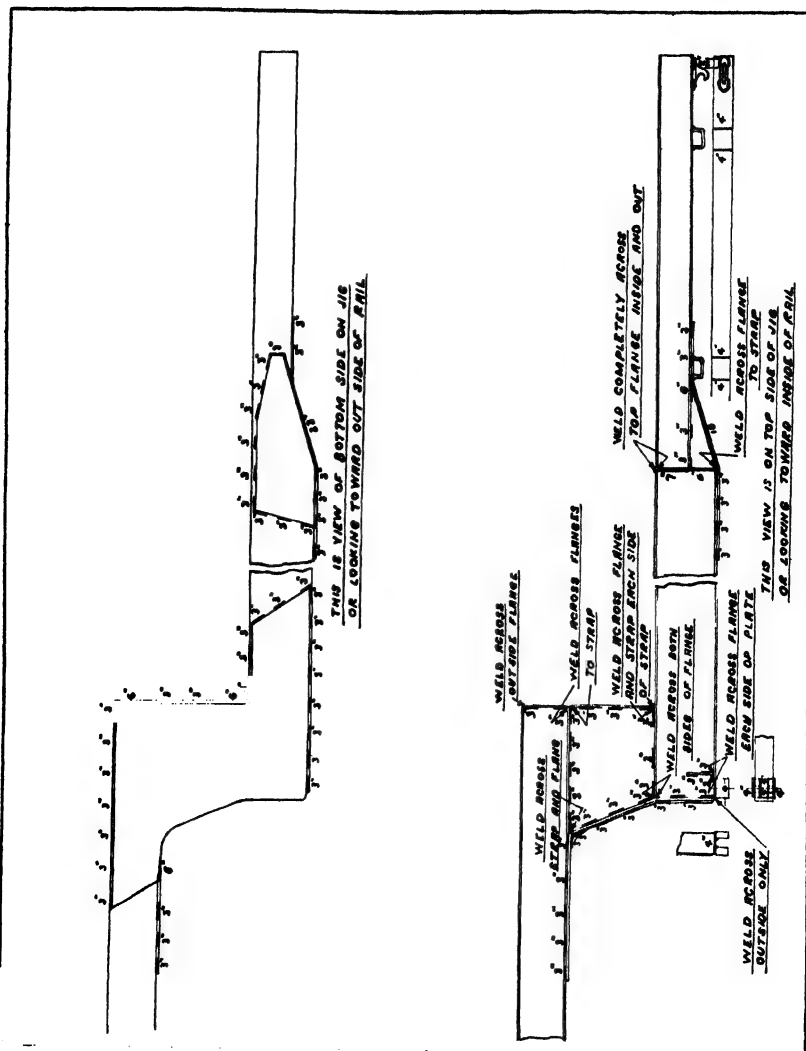



Fig. 12. View on top side of jig.

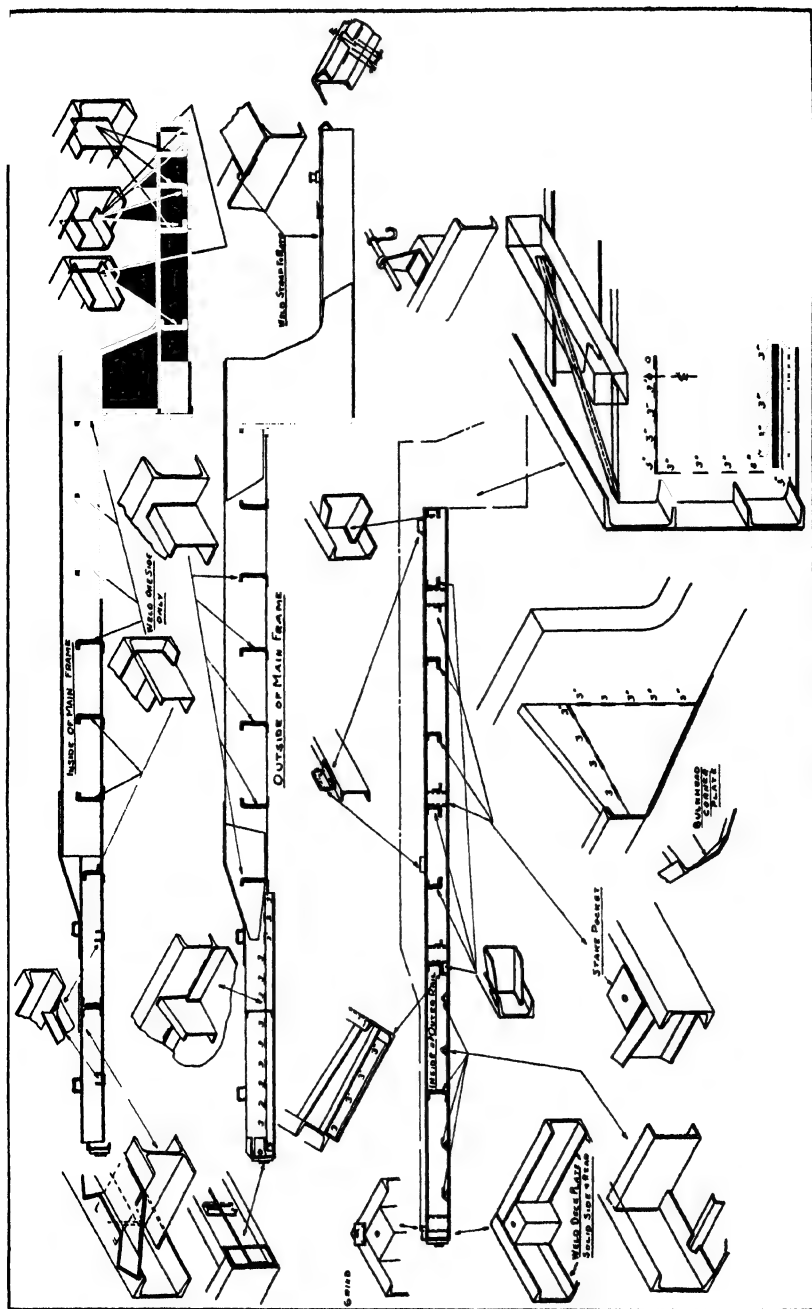



Fig. 13. Main assembly.

with a larger rear rail than before by allowing the trunnion bracket to be level with the bottom of the rail.

The outer rail joint on the original design, (See left, Fig. 10), was riveted and due to the overall width being kept as close to the maximum allowable, the outrigger-outer rail fastening was made with corner angles and flat-head rivets through the outer rail.

Driving these outer rivets caused the rail to get out of shape longitudinally so welding was resorted to which took care of this condition and developed a satisfactory joint, (See right, Fig. 10). In addition, 80 holes and 40 rivets were eliminated.

The assembly of the rear corner joint was previously accomplished by notching the rear cross member, fitting and corner angling, and the skid rail was riveted on with spacers in place requiring for this assembly, 28 rivets and 60 holes, (See left, Fig. 11).

The notching of the cross member was eliminated by using a wide outer spacer and welding from the inside.

The parts were so positioned that the welding made rounded corners requiring little finish.

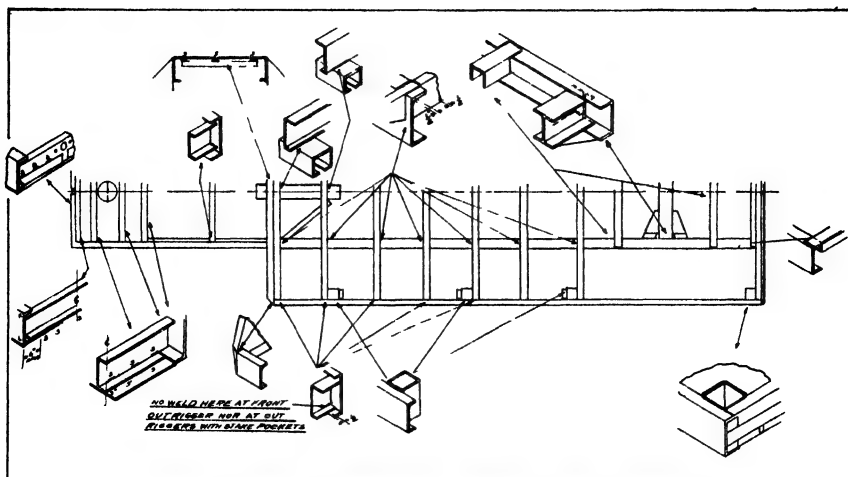



Fig. 14. Frame is revolved and welded on upper surfaces.

Controlling the Duplication of Proper Weld—The analysis of welded joints showed we could standardize on ¼-inch fillet welds providing they conformed to an exact pattern and were made properly.

To insure this, was made a welding diagram for each jig in perspective where necessary, so that all joints would show clearly and in their position in the jig. Where the weld was skip type, exact amount was shown.

Jigging for Speed and Space Savings—It was determined from examination of the unit in feet of welding and loading time estimated, that certain subassemblies, such as the side rails should be made in separate jigs.

The Side Rail—The side rails are welded in a jig in which it was determined one jig making right and left units would suffice for the reproduction required.

The rails are originally placed in the jig with plates under the channel and welded as shown in Fig. 12, at bottom.

The rail is then turned over and welding completed on the reverse side as shown in Fig. 12, at top.

The locating points on the jig holds the proper dimensions for further assembly in jigs.

Other subassemblies were rear rail, wheelhouse plate, and trunnion shaft support. These were jigged in the same manner as the side rail.

The main assembly is made upside down and welded as shown in Fig. 13.

It was found practical to weld the outriggers, cross members and bulkhead vertically since the design provided the maximum stress be taken on welds made in the flat position.

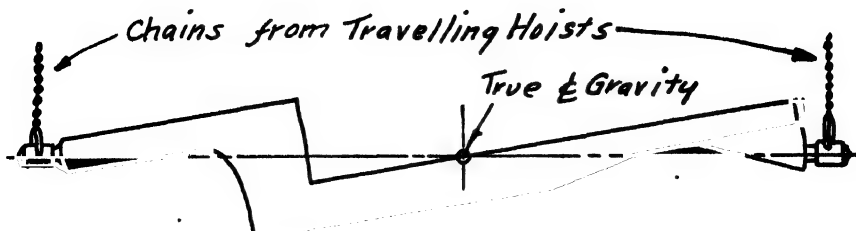



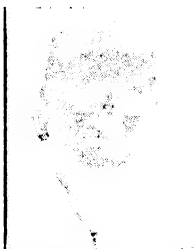
Fig. 15. Two traveling hoists lift and rotate the unit for welding.

After removal from the main fixture, the frame is revolved and welded on the upper surfaces as shown in Fig. 14. This revolvement is accomplished as follows: The exact center of gravity of the unit was found by calculations and a line was drawn through where trunnions would allow balanced rotation. In the hole for the electric plug on the front, was inserted a trunnion bar and the rear trunnion was clamped on the skid bar.

The unit is picked up out of the jig by two travelling hoists and is rotated readily by hand for welding the upper surface, (See Fig. 15).

Chapter XI—De Luxe House Trailer

By GEORGE J. GRAVES,

President, Graves & Son Boiler & Mfg. Co. Inc., Jamestown, New York

George J. Graves

Subject Matter: Trailer is rounded in front curving back over the roof in a streamlined effect. The base channel is 1 x 2 x 1/8 inch, supporting 1 x 1/2-inch upright channels which carry the 20-gauge steel plate surface. A positive ball-and-socket hitch is provided to the auto, giving good control on the road, and hydraulic brakes are provided on the two rear wheels. The cost without profit is $702. The interior equipment is all readily removable, allowing trailer to be used for other purposes.

Before attempting to build this trailer, the author devoted considerable study to the conventional type of trailers now in use, to the extent of inspecting the interior and exterior of practically all makes. On a recent trip to Florida, an extensive tour of nearly all the trailer camps, and made notes of all the variety of designs, construction features, etc., also taking particular notice as to the road-ability of trailers on the highways, and finally came to the following conclusions:

90 per cent of all covered trailers are built of wood framing, canvas and plywood cheaply constructed and of short life; most designs are homely, have made no provision for wind resistance, and are usually found on highway, bobbing and swaying; to the motorist passing by, they give the impression, they are about ready to take off or roll over; it is true most trailers are designed to have all the comforts of home, but who wants a home in a trailer; outside of Florida and the wide-open spaces of the West, there are only a few places where people are allowed to park them; living in a trailer camp, crowded together with limited sanitary facilities may appeal to a few of our Americans but I am sure the majority object to living like gypsies.

So, to invest money in a trailer to be used entirely for living purposes was "out" as far as the author was concerned.

Now there is no form of recreation enjoyed by the masses of Americans today any more, than the use of their automobiles to take trips near and far. Tourists are always confronted with the problem of, "where do we sleep now". Then there is the sports-lover who every year enjoys fishing, hunting, boating, camping or vacationing in some form of other, who also is confronted with the same problem of, "where do we sleep now". This applies to salesmen and peddlers who have large territories to cover, and carry their samples with them for display purposes, to merchants, distributors, advertising organizations, tradesmen, craftsmen, etc.

All these and more are potential outlets for a trailer of the covered type.

With these thoughts in the mind of the author, and the fact that he would like to own a trailer, to travel in, use for camping, hunting, fishing

Fig. 1. Angle view of trailer showing portion of front and side.

trips, and when not in use for this purpose, to use in connection with his business as a means of transporting equipment and for display purposes, the writer was prompted to make plans for the immediate construction of a trailer. At this stage, there was the matter of determining the size most practical, design to conform with the streamlined trend, strength, weight, cost and, in general, to produce a product superior to any as yet placed on the market.

With a background of many years of welding experience, and the fabrication of metals, using the arc welding process for 95 per cent of our work, the author presents the results of what was accomplished in the following study of his product.

The picture in Fig. 1 is an angle view which shows a good portion of the front and side. It is attached to car and clearly shows the level-running position, due to correct trailer balance.

Note: In the accompanying pictures, arrows are used to point out certain features. Arrows will refer to different items in each picture, and, in all, will completely describe trailer.

Fig. 2 illustrates comparison of overall size, to the size of automobile. "A" is the total length of body of trailer, which is 12 feet. "B" is the clearance

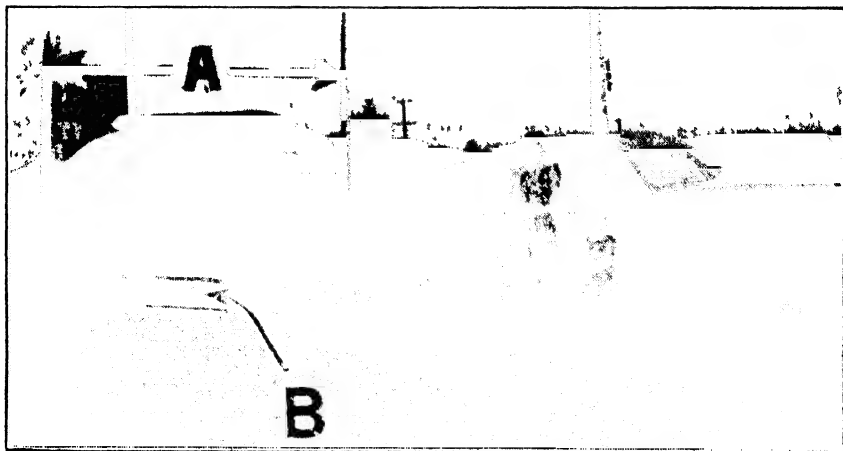



Fig. 2. Size comparison of trailer and automobile.

from road load 12 inches, with all equipment removed 15 inches. Incidentally, part of the author's family is also shown in this picture. This was taken on a motor tour of 2500 miles, covering a period of two weeks and all of the nights were spent sleeping in this trailer. Parked off the main highway, the trailer was never detached from the car. Cruising speed averaged about 50 miles per hour, and when the going was good was increased to 75 miles per hour. At no time was the car or trailer out of control. In fact, drag on car was hardly noticeable, and on only a few occasions was it necessary to shift into second gear. According to gasoline mileage on car, it amounted to a difference of 1 mile less to a gallon.

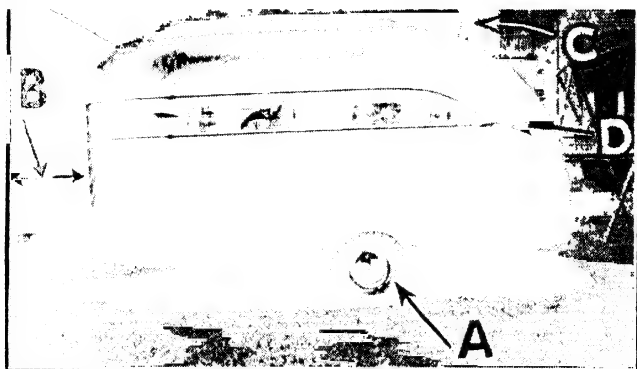



Fig. 3. Direct side view of trailer.

Fig. 3 is a direct side view at close range. "A" is a low-pressure tractor tire, 10-inch rim, 24 inches outside diameter, 7½-inch width. Tire is designed to carry 1500 pounds at 30 pound air pressure, giving an excellent cushioning effect. "B" is the distance from body of trailer, to center of ball connection, which is 24 inches and is necessary for sharp turns. It is possible to "jack-knife" trailer when it is attached to car. "C" is a ventilator, 10-inch diameter, using a hub cap same as on wheels, and is arranged so it can be opened from inside of trailer. "D" is one of the four running lights, red for back, and amber for front.

Fig. 4 illustrates the means of entering trailer. "A" shows how ventilator swings open. It has a locking device to adjust to any desired opening. "B" is the rear entrance door which swings up like the trunk on a car and is held in open position by coil springs. Height of trailer floor from ground enables person to step into trailer easily. "C" is standard car hub cap which forms center of wheel, and is held on with spring steel clips.

Photo, Fig. 5, was taken from ladder, and clearly shows view of top, back, and side. "A" is stainless steel molding secured from an automobile dealer, and is bolted through steel covering of trailer. "B" is the rear window, cut from ¼-inch plate glass. Rear window is permanently set in a rubber channel and, cemented into place, is held by steel lugs. The two front side windows are made so they can be removed and replaced with a screen. However, as there is ample ventilation provided by rear door and top ventilator, it is not necessary to open any of the windows.

In Fig. 6 is another view taken from a ladder, showing top and back. "A" is a rubber strip which covers joint at top of door to prevent rain water from entering trailer.

"B" indicates the welded seams on roof of trailer, which are the most difficult to weld. They are the lap type of joint.

Fig. 7 shows front and side view. "A" is a small third wheel, used for supporting front of trailer when not attached to car. Wheel and tire are of the type used on wheelbarrows. The bracket holding wheel is made from steel plate, and has a stub shaft welded to it and extends through tube insert as shown at "B" allowing wheel to turn like a caster. "C" is the front window made from a piece of ¼-inch plate glass and curved to conform with radius of trailer. "D" is the side panel which is the only flat panel on the entire trailer. Sheet steel covering is 20-gauge throughout.

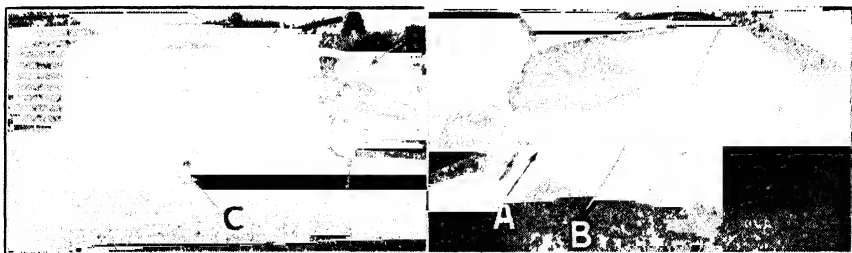



Fig. 4, (left). Means of entering trailer. Fig. 5, (right). View showing top, back and side.

Fig. 8 is a front view with "A" as the overall width which is 72 inches, or the same width as the car towing trailer. By limiting width of trailer, to that of car the driver can maneuver through traffic without the danger of side-swiping other vehicles on the road. There are many instances when cars pass each other by only inches to clear. "B" is the brake arm extending through front extension of trailer. It is attached to master cylinder which regulates hydraulic brakes on trailer. A cable is attached to this arm and brakes are applied mechanically from the driver's seat.

Fig. 9 is a direct rear view, with "A" showing width of door 36 inches, height 60 inches. Opening of this size permits easy access, and is large enough to allow bulky materials to pass through, such as furniture, boxes, etc. "B" is the space required for bunks, 26 inches from each side, and consisting of lower and upper, or accommodations for four people. "C" is the space between bunks which form an aisle 18 inches wide, leading to the front section of trailer.

Fig. 10 is a front and top view taken from a ladder. "A" is the ventilator tube which extends through to inside of trailer. A small fan can be mounted in this tube, increasing air circulation. "C" is the junction of front extension body of trailer. This joint is also welded.

Fig. 11 is another direct rear view, with "A" as the height from floor to top of dome, which is 72 inches inside headroom of trailer. "B" is the dome section of top which allows people to stand in an upright position, after they have entered through the rear door. "C" is cap for ventilator which is fitted with a rubber gasket for tightness.

Fig. 12 is a front and side view showing framework just as it was ready for covering. "A" is a forged steel trailer hitch consisting of ball and socket, securely welded to steel frame members. "B" is the light upright channel ½-inch by 1-inch made from 16-gauge strip steel. The entire upper frame work is made of this channel. "C" shows the front roof channels, how they

are bent, and spaced equally around the entire front. Exterior steel covering butts together at each of these roof channels.

Fig. 13 is another side view picture of framework. "A" is a section of covering sheet steel 20-gauge tack welded onto braces from the inside, approximately 2 inches on centers, tacks ¼-inch long, and arc is applied mainly on 16-gauge channel to prevent burning through 20-gauge steel. "B" is the housing covering wheels, made from 10-gauge steel, and also carries entire weight of trailer. "C" is the outside channel 1x2x⅛-inch. This channel forms part of frame and extends around entire trailer. "D" is upright channel ½x1x16-inch gauge. "E" shows brackets and rollers that hold door in open position. "F" are coil springs fastened to brackets and trailer framework to furnish tension to hold door open.

Fig. 14 shows back view of frame work. "A" are bent channels forming the back curve. Channels are bent to 18-inch radius. "B" is the rear bumper salvaged from a late model wrecked car. "C" is a small rear view window, permitting rear vision to driver of car. This window is in direct line with front window, and makes it possible to see the road from driver's seat in car.

Fig. 15 shows front view of framework. "A" shows arrangement of bent channel bars to form dome. "B" is the front window bars in this frame arranged to hold curved glass. "C" are bent channels which form rounded roof. These bars are equally spaced on 7-inch centers. "D" is conical cover of frame extension. Hydraulic brake mechanism is mounted under this hood.

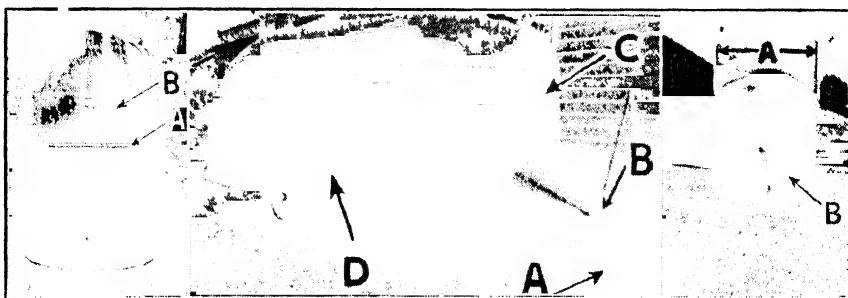



Fig. 6, (left). Another view of the top and back. Fig. 7, (right). Front and side view. Fig. 8. Front view.

Fig. 16 is a close-up of axle and trailer mounting taken with wheel removed. "A" is hydraulic shock absorber, salvaged from wrecked car. "B" is brake drum, brakes and axle spindle, also salvaged from Plymouth car. "C" is trailer mounted on two coil springs, salvaged from Buick car. Springs will carry a combined load of 3000 pounds and only be 50 per cent compressed. "D" is a built-in plate support where springs rest on. "E" is one of 2 type rods holding axle in line, arranged to move up and down by ball and socket joints. In addition to these features there is a sway bar, attached to axle and trailer body, preventing side sway.

Fig. 17 is a close-up of car and trailer. "A" is one of two safety chains required by law to prevent trailer from leaving car in the event of a broken hitch. "B" is the brake cable which is threaded through center of trailer hitch. Tension on this cable is always the same regardless of angle of trailer "C" is bracket and ball-and-socket hitch. Bracket is securely attached to frame of car. Hitch is a steel ball and forged steel socket.

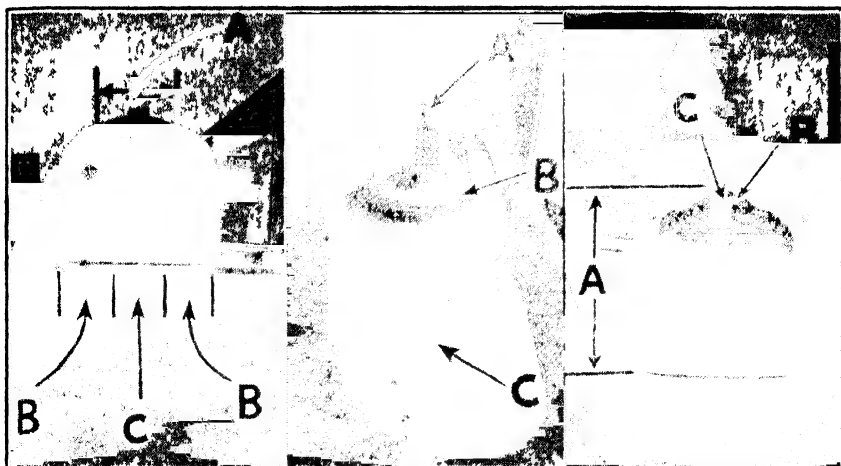



Fig. 9, (left). Rear view. Fig. 10, (center). Front and top view. Fig. 11, (right). Rear view.

Cost Sheet of Trailer—The list includes all materials and labor for complete trailer, exclusive of any interior furnishings such as bunks, cupboards, sink, refrigerator, stove, etc.

As trailer is designed for a number of uses, it is not essential that furnishings be included.

All materials are listed in the order they are to be used.

Item	Cost
Running Gear—Tires, tubes and rims	$ 50.00
Hubs, spindles, brakes	15.00
Parts salvaged from car, extra heavy pipe axle	2.00
Shock absorbers, springs	5.00
Third wheel tire, hub and axle	9.60
Steel channels for main frame	6.75
Steel channels for upper frame work	13.35
Oxygen and acetylene, welding electrodes	10.00
Sheets 20-gauge to cover bottom of main frame	5.45
Sheets 20 gauge patent level for covering exterior	24.00
Paint for finishing outside of trailer 4 coats	9.50
Paint for rust proofing inside of trailer	2.00
Glass ¼-inch plate for windows	12.00
Rubberchannel for setting glass into frames	2.50
Rock wool insulation to insulate floor	4.00
Plywood ½-inch thick flooring	16.00
Inlaid linoleum for floor covering	15.50
Running lights, tail, direction and interior	14.00
Stainless steel molding for trim	7.50
Rock wool insulation for walls and ceiling	8.50
Electric wires for lighting	3.50
Plywood for interior trim and moldings	25.60
Varnish for interior finishing	3.85
Miscellaneous, screws, bolts, paste, etc	5.00
	$270.60
Total cost of all materials	$270.60

Man hours for construction of running gear	24 hrs.
" " " construction of frame work	63 hrs.
" " " applying metal covering	38 hrs.
" " " finishing exterior	26 hrs.
" " " electric wiring and install fixtures	12 hrs.
" " " lining and insulating interior	47 hrs.
" " " interior finishing	16 hrs.
	226 hrs.

Cost of labor 226 hrs. at $1.00 per hour	$226.00
Overhead of average Mfg. Co. 100 per cent of labor	226.00
Total manufacturing cost	$702.00
Manufacturers profit and sales cost 33⅓ per cent	234.00
Sale price to consumer or user	$946 00

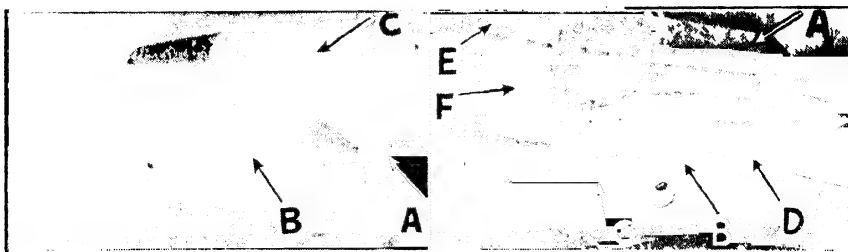



Fig. 12, (left). Front and side view showing framework ready for covering. Fig. 13, (right). Side view of framework.

Cost of materials and hours of labor as stated herein are true and accurate. The overhead percentage of profit and sales cost may vary to some extent in the case of some manufacturers. However, as cost of materials and labor are based only on the construction of one trailer, it is entirely possible to construct and place on the market, a trailer of this size and type, well under $1000 and assure the manufacturer of a greater percentage of profits when building them in quantity.

To the man or individual who may desire to build this type of trailer, and who has the ability, can be assured the materials will not exceed $300 wherever he may wish to purchase them. This does not include equipment such as bunks, stove, sink, refrigerator, cupboards, etc. For a trailer of this size, an additional cost of approximately $200 will suffice.

Cost Comparison—Due to the fact this trailer is of unique design, 75 per cent steel and of welded construction, it is difficult to compare costs with the conventional designs now on the market. However, prices on trailers range from $600 to $1500 depending on size. Then the cost of this trailer is well in line, and with the advantage of indestructible lifetime construction, over the conventional types.

Construction Features—From the accompanying pictures note that the only flat panels on this trailer are the 2 sides. In designing trailer, the author knew that light sheet steel is inclined to warp, buckle, and twist when welded, and to eliminate this it was necessary that curves be used wherever

possible. There were no jigs, fixtures, or dies used to form any part of this unit. The only equipment necessary is an arc welder, an oxy-acetylene outfit, a flat-top table, hacksaw, and vise. However, from a production standpoint, it is entirely possible to build dies, and press out the rounded surfaces, thus reducing material, and labor costs considerably. All joints of framework were arc welded together, and 20-gauge sheet steel covering was clamped into place and tacked from the inside, tacks approximately 2 inches on center and ¼-inch long. In tacking, considerable skill was required to prevent burning through sheet steel.

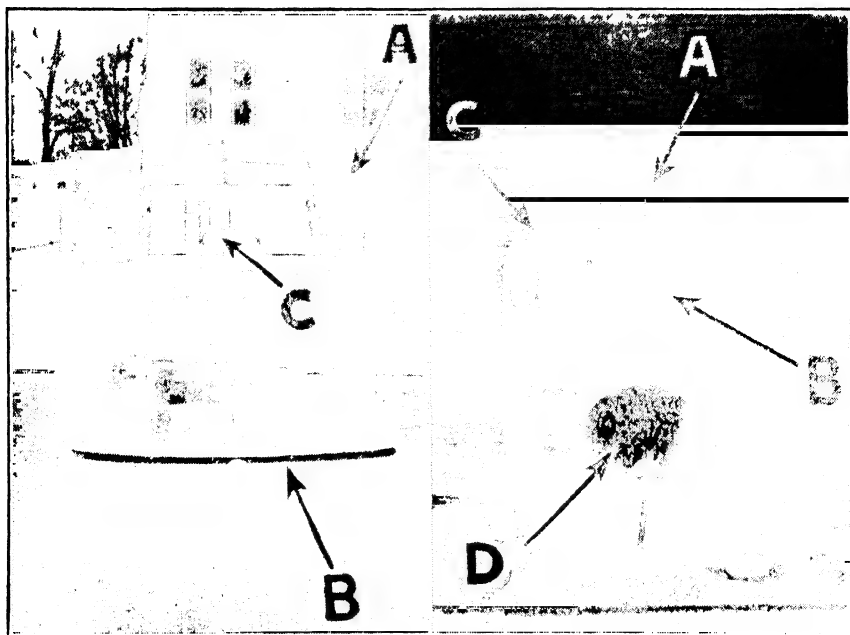



Fig. 14, (left). Back view of framework. Fig. 15, (right). Front view of framework.

The work of finishing the inside involved considerable time and patience. First, it was necessary to lay rock wool insulation in pad form in the 1-inch space formed by channels, on all sides and roof. Also the 2-inch space under the floor was filled with granulated rock wool. Then plywood ½-inch thick was placed directly on channel frame, and screwed down using self-threading screws. On top of this plywood floor, a red-colored inlaid linoleum was cut to fit and glued into place. For the side walls and ceiling, ⅛-inch birch plywood was fastened to inside of 1-inch channels and held in place by self-threading metal screws. A ½-inch half-round wood molding covered all butt joints of plywood. Then, entire interior was sanded and two coats of varnish applied.

Total weight of trailer at this point is 1755 pounds.

Interior Equipment—Due to the diversified uses of this trailer, the author designed all interior equipment so it could be removed. Self-supporting bunks were made of light-weight tubing, and equipped with springs.

Bunks are placed on both sides, providing two lower and two upper berths, making accommodations for four people. During the day, upper

bunks swing up and hook to ceiling providing seating space for eight people.

In the forward end of trailer, there are three units built to dovetail into rounded front, consisting of single-burner stove, sink and refrigerator. The tops of these units form a circular counter, and the bottom cupboard space, and a place for a small tank of fresh water.

In the rolled section at rear of trailer there is space for clothes presses. The space under the lower bunks is used for linens, blankets, clothes, fishing tackle, etc. This equipment is arranged so it can be removed from trailer in 15 minutes, permitting the entire interior to be used for any purpose owner may wish.

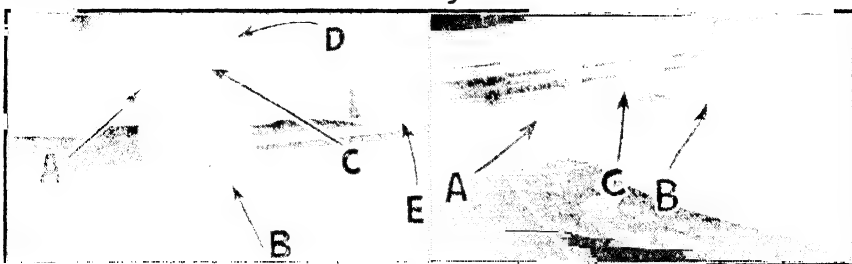



Fig. 16, (left). Close-up of axle and trailer mounting. Fig. 17, (right). Close-up of car and trailer hitch.

Advantages—The dimensions of this trailer enable driver of car to maneuver more easily, get in and out of inaccessible places. One person can push it about when detached from car. In traffic, it is possible to go wherever car can pass, because it is the same overall width as car. Trailer has advantage of less weight due to size and can be towed with less resistance and at greater speed. Streamlined design and low overall height cut down wind resistance. The design of running gear permits higher road speed with assurance of safety. Coil springs give knee action to each wheel, shock absorbers take care of rebound, and sway bar prevents body from swaying. The all-welded steel construction will assure user of years of service and will not fall apart from road shock.

Uses and Potential Market—This trailer was designed primarily for use on our highways for people who travel by car, including tourists, vacationists, salesmen, campers, hunters, fishermen, etc.

In addition to traveling, it can be used for commercial purposes, such as making deliveries of merchandise, farm produce, display purposes, field offices, particularly, at this time when the army is spread out over half the universe. The army could use a trailer of this type for officers' quarters, field office, first-aid, Red Cross, and any number of uses where a roof over the head is essential.

There is still another purpose this trailer can be used for and it would not occur to the average person. The trailer body can be used as a cabin for a boat. It is the intention of the author to build a shallow-draft all-welded steel hull, and mount trailer cabin on same, for use on inland lakes and rivers. If it were not for our country entering the war and placing a restriction on steel, this idea would have actually become a reality before now.

SECTION II
Aircraft

Chapter I—Welding Aircraft Engine Mounts Economically

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Peter F. Rossmann

Subject Matter: Economics of arc welding based on a comparative study of another method and arc welding under shop conditions. The comparison covers quality, speed, and cost and indicates marked superiority of arc welding in all three items.

The contents of this paper are based on the results of exhaustive studies and tests to make comparisons of arc welding and another method of welding in the manufacture of aircraft engine mounts. The research which was under laboratory and time-study control under actual shop conditions treated the comparisons in terms of:

I—Quality II—Time III—Cost

The other method of welding as performed at this company is under the control of the Materials Laboratory Procedure, "Control of—Welding." Arc welders are required to pass the same tests as are other-method welders and it has been demonstrated that a welder experienced with the other method can be trained to qualify as an arc welder within a period of 15 days.

This comparison was made using present design standards. Because of certain difficulty with fusion and penetration with former method of welding heavy forgings to thin-walled tubing, current design standards for the former method are believed to be extra-heavy with respect to arc welding, because the latter process can produce comparatively superior welds.

This research project disclosed the merits of arc welding and the results emphasized advantages from which the following general conclusions were drawn:

I—Quality—Arc welding motor mount assemblies performed as outlined in this report, produces welds superior in quality.

II—Time—Arc welding would save approximately 73 per cent of the time now required to weld these assemblies.

III—Cost—Arc welding would save approximately 75 per cent of the present cost for welding operations of these assemblies.

Preparation of Samples—Welding Procedure

Other Method of Welding—All welded samples were prepared in production by standard company welding procedure.

Arc Welding—The arc welded samples were prepared by using interchangeably the arc welding equipment listed in Reference 12.

After setting in jig and tacking, all parts were preheated with an acetylene torch to 300°-400°F before welding.

Parts A and B in Fig. 1 were welded with 5/32-inch electrodes, and a welding current of approximately 150 amperes at 40 volts.

Parts C, D, E, F and G in Fig. 1 were welded with 1/8-inch electrodes, and a welding current of approximately 110 amperes at 40 volts.

Note—Electric arc welding presents some problems of safety on the part of the operator and workmen in the immediate area of the welding. Proper arc welding shields are required for eye protection of the operator. Each operator should be screened off with fire-proof canvas or other proper booth to prevent eye injury to other operators or workmen in the immediate area of welding. Proper electrical installation eliminates dangers which possibly may be present due to electric power supply for A.C. or D.C. welders.

Analyses of Deposited Weld Metal vs. Original Rod or Electrode—Drillings of deposited weld metal were taken outside the zone of fusion with base metal. The analyses are shown in Table I.

Table I—Analyses of Deposited Weld Metal vs. Original Rod or Electrode

Qualitative Analysis of Coatings	Former Welding Method			Arc Welding Method — Electrode			Arc Welding Method — Electrode		
	Spec. Ref. 6	As Recd.	As Deposited*	Spec. Ref. 6	As Recd.	As Deposited*	Spec. Ref. 6	As Recd.	As Deposited*
C%	Copper coated	Copper coated		Sold as a proprietary "alloy" rod, "Planeweld"	Present		Specified only as "flux"	Present	
Si					Present			Present	
Fe					Present			Present	
Al					Present			Present	
Ca					High			High	
Mg					High			High	
Ti					Trace			Trace	
Mn					4.5% (?)			2.85 (?)	
P					Low			Low	
S					Low			Low	
Mo					High			Trace	
Ni					Trace			Trace	
Cu					Present			Trace	
Cr					Trace			Trace	
W					Present			Trace	
V					Present			Trace	
Quant. Anal. of (Metals) %							1E–2E 5E–6E		
C	.06 Max.	.04	.07		.10	.08	.10–.18	.12	.08
Mn	.25 Max	.12	.10		.51	.35	.30–.60	.53	.30
P	.04 Max.	.015	.012		.009	.027	.04 Max.	.007	.013
S	.05 Max.	.016	.013		.031	.010	.05 Max.	.022	.017
Si	......	.01	.01		.01	.023	.08 Max.	.01	.025
Ni	......	......	......		.06	......	......	.06	......
Cr	......	......	.05		Trace	.06	......	Trace	.06
Mo	......	......	Trace		.01	1.02	......	.04	Trace
V	......	......	......		......	.12	......	......	......

(*) Will vary depending upon the extent of puddling with base metal.

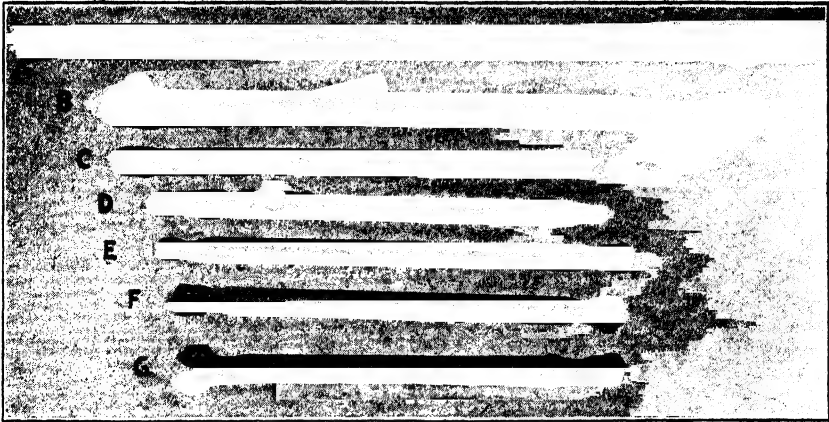



Fig. 1. Collection of arc welded plane parts.

Sampling

1.—Several motor mount sub-assemblies welded by the other method scrapped by inspection and salvage departments for various causes.

Base Materials to References 4 and 5.

Control procedure to Reference 1.

Standard Company blue print heat treatment, after welding, to tensile strength of 150,000 PSI.

2.—One complete arc welded motor mount assembly and several sample sub-assemblies.

Base Materials to References 4 and 5.

Control procedure to Reference 1.

Standard Company blue print heat treatment, after welding, to tensile strength of 150,000 PSI.

Table II indicates the various tensile strength and hardness readings of representative cross sections of welded samples.

Table II—Tensile Strength and Hardness Readings (See Fig. 2)

Tubing and forgings indicate similar hardness in each case, since all were heat treated to a tensile strength of 150,000 PSI minimum. (Desired Rockwell hardness of C32 to 36).
Weld metal hardness may be tabulated as follows:

Rod, or Electrode	Range		Estimated Average	
	Rockwell	Estimated Equivalent T.S. PSI	Rockwell	Estimated Equivalent T.S. PSI
Conventional Deposited Rod	B64 to 94	57,000 to 100,500	B80	74,000
Arc Deposited Electrode	C22 to 31	118,500 to 146,000	C25	126,500
Arc Deposited Electrode	B85 to 95	80,700 to 102,400	B90	91,800

These diagrams also illustrate the superior penetration and superior fusion of the arc welded samples, when compared to those welded by the other method.

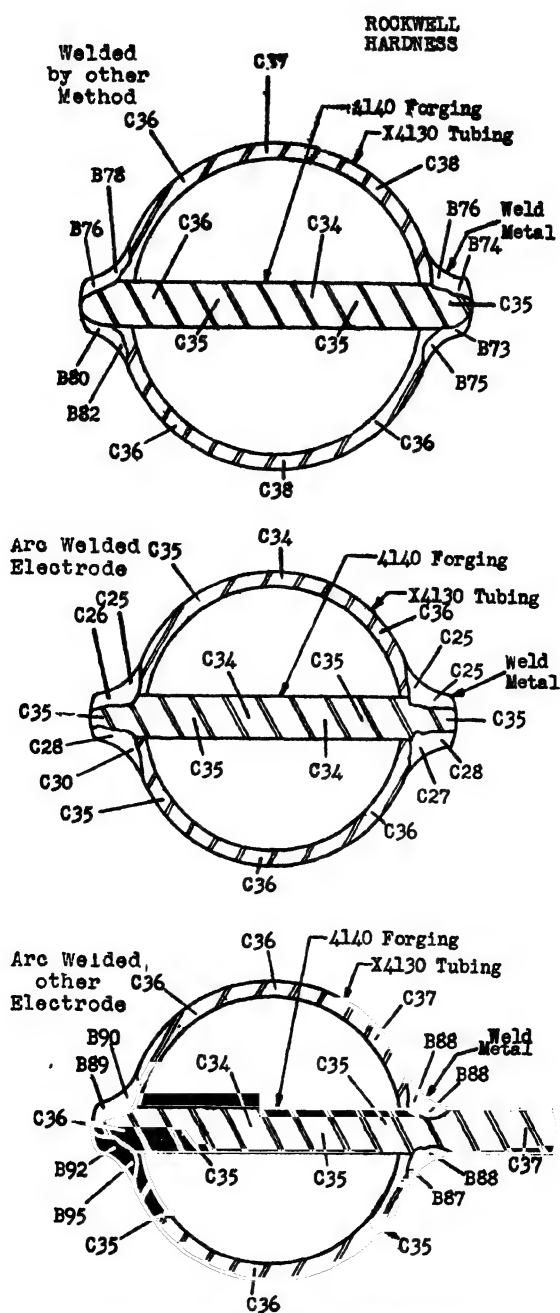



Fig. 2. Three types of welds compared.

Fig. 3. Deep-etched assemblies welded by the former method (left), and arc welding (right).

Terms of Comparison

I—**Quality**—Quality tests were based upon exterior appearance, and appearance of deep-etched cross sections, the latter with respect to fusion, penetration, porosity (density) (and also Rockwell hardness as heat treated).

Sampling—Several assemblies (both arc welded and other method) such as shown in Fig. 1 were used for these determinations.
Results—Exterior Appearance—Fig. 3 illustrates one sample each, other method and arc welded, forging to tube, Part B.

Note—A similar exterior appearance was attained with either of the arc welding electrodes.

Deep-Etched Cross Sections—In Fig. 4 is shown a representative series of three each, other welded and arc welded sections, after deep-acid-etching (50 per cent aqueous HCl).
The three other welded samples are representative of 12 samples by eleven operators.
The three arc welded samples are representative of 40 samples by a single operator.
Density, fusion and penetration is superior in the case of the arc welded specimens. These remarks are more clearly illustrated in Fig. 5, at a magnification of 3 times.

Note—The macro etches indicated the metal deposited by arc welding to be finer grained than that deposited by the other method of welding (both metals with similar final heat treatment, as indicated).

II—**Time**—The time study experiments involve the seven assemblies shown in Fig. 1, and were comparative, other method vs. arc. The comparative time studies involve actual welding time, plus an allowance in each case of an amount equal to approximately 30 per cent of the total (Total = Operation Time plus Allowance). This 30 per cent includes time requirement for tacking, straightening, cleaning in the case of arc welding, and delays and relaxation.

Other Welding—These were taken from time study department records (Reference 8).

Arc Welding—These were taken from a set of experimental welds, performed and timed by separate personnel.

Time required for total welding operations, plus allowances, is shown in Table III.

III—**Cost**—For a unit of cost comparison, one set of one each of the seven assemblies shown in Fig. 1 was chosen (which was the same unit taken for the time comparison).

For each case, other method and arc, costs were tabulated on the basis of material, labor and equipment, not including burdens.

Table III—Time Required for Total Welding Operations, Plus Allowances

Parts Fig. 1	(A) Other welding, plus tacking and straightening and allowances. Company time study in minutes.	(B) Arc welding, plus tacking, cleaning welds, and straightening, and allowances. Experimental time study in minutes.
A	275	80
B	517	125
C	76	25
D	220	65
E	140	35
F	132	40
G	128	35
Total	1356 minutes	365 minutes

Arc welding saves an average of 73 per cent of time needed for welding the set of assemblies by the other method.

Arc Welding

1. **Material**—Under this charge was included power cost and electrode cost.

The power for electric arc welding of each sub-assembly was determined by taking the amperage and voltage settings needed for welding each assembly and making use of the formula KWH—volts x amperes x time in hours. Cost of power was then determined by multiplying number of KWH by price per KWH.

Electric power in KWH to operate an electric welder at 150 amperes and 40 volts, for one hour, is: $KWH = \frac{150 \times 40 \times 1}{1000}$, or 6 KWH.

To operate the same welder at 100 amperes and 40 volts for one hour requires: $KWH = \frac{110 \times 40 \times 1}{1000}$, or 4.4 KWH.

Electric power on 60 cycles, 440 volts for the company costs $0.015 per KWH. Therefore, to operate an arc welding machine at 150 amperes and 40 volts for 1 hour costs: 6 × 0.015 or $0.09. The same machine at 110 amperes and 40 volts costs: 4.4 × $0.015 or $0.066 per hour.

Electrode consumption was estimated as 12 pounds maximum for the set of seven assemblies. Electrode cost then equals:

12 × .09* = 1.08 for —electrode
12 × .25* = 3.00 for —electrode
(* Costs per lb. — Reference 9)

2. **Labor**—An estimated labor cost of $1.10 per hour, similar to that for other welding was made for this work.

3. **Equipment**—Arc welding equipment may be listed as welding machine, cable, electrode holders, shield or helmet, gloves, and booth partitions. Purchased new this equipment would cost an estimated maximum of $450. For 6 hours of welding, equipment costs were estimated as $.07 maximum.

Material and Equipment Costs for Preheating and Line-up—These charges were estimated as $1.00 for the set of assemblies. (This figure is nearly 15 per cent of the remaining total costs and may, therefore, be regarded as a liberal maximum.)

The cost of arc welding is shown in Table IV.

Summary—A comparison of the tabulated costs for other vs. arc welding indicates respectively a ratio of 4 to 1, i.e., torch welding costs four times that of arc welding; or, if other welding is considered a unit, then arc welding shows a 75 per cent reduction.

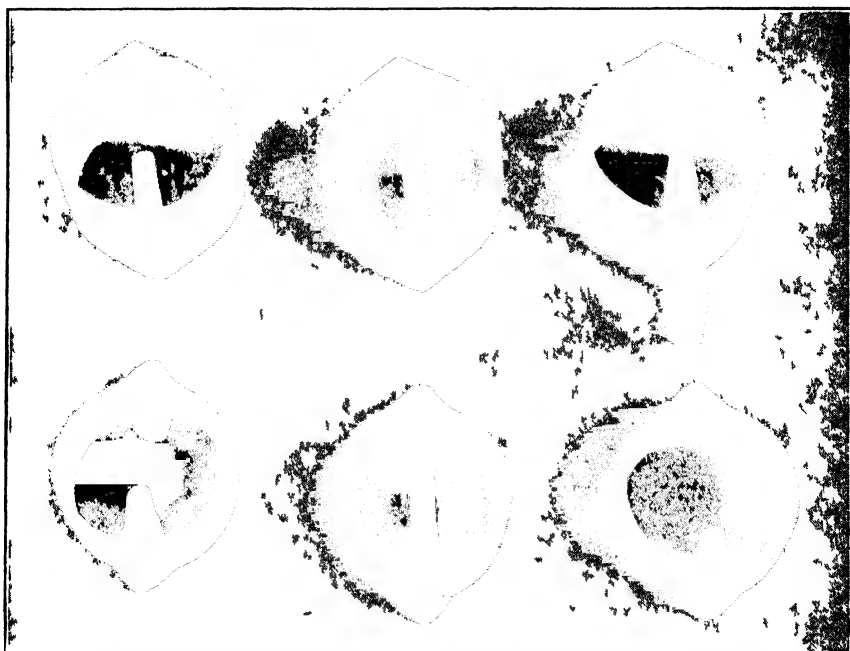



Fig. 4. Deep-etched cross sections welded by the other method (above), and by arc welding (below).

Table IV—Tabulated Arc Welding Costs

This table shows the cost of labor and power for arc welding each of the sub-assemblies in question; and to the total has been added the cost of electrode, of equipment, and of material and equipment costs for preheating and line-up.

Part Number (Fig. 1)	Welder Setting		Actual Welding Time — 70% of Experimental Time Study	Cost of Power (150A — 40V = $0.09/hr.) (110A — 40V = $0.07/hr.)	Cost of Labor ($1.10/hr. or $0.0183/min.)	Total Cost of Labor and Power
	Amperes	Volts				
A	150	40	70% of 80 min. = .56 min.	.83 × $0.09 = $0.075	80 × $0.0183 = $1.464	$1.54
B	150	40	70% of 125 min. = 87.50 min.	1.5 × $0.09 = $0.135	125 × $0.0183 = $2.29	$2.42
C	110	40	70% of 25 min. = 17.50 min.	.3 × $0.07 = $0.021	25 × $0.0183 = $0.457	$0.38
D	110	40	70% of 65 min. = 45.50 min.	.75 × $0.07 = $0.053	65 × $0.0183 = $1.19	$1.24
E	110	40	70% of 35 min. = 24.50 min.	.5 × $0.07 = $0.035	35 × $0.0183 = $0.64	$0.68
F	110	40	70% of 40 min. = 28 min.	.5 × $0.07 = $0.035	40 × $0.0183 = $0.73	$0.77
G	110	40	70% of 35 min. = 24.50 min.	.5 × $0.07 = $0.035	35 × $0.0183 = $0.64	$0.68
Totals			70% of 405 min. = 284 min. = electrode time		405 min. = $7.41	$7.71

Estimated electrode cost for the total = 12 × .09 for Electrode .... $ 1.08
Estimated equipment cost for the total = ... .07
Estimated material and equipment costs for preheating and line-up 1.00
Total arc welding cost for the set, including material, labor and equipment, but not overhead .... $ 9.86
Note:—For—rod, the total is $10.18

Comments for Discussion

Tendency for Cracking—No cracks in welds or adjacent to welds were found in any part used in these tests, either other-method or arc welded. Preheating is an effective preventive for weld cracking.

Preheating—It is noted that with arc welding of these parts, the oxy-acetylene torch is useful for preheating. The costs of this operation have been included in the total costs for arc welding, as tabulated in Table IV.

Weld Cleaning—Other welding requires no cleaning by welders while arc welding requires approximately 10 per cent of welding time by welder to remove slag and spatter, and to examine weld. This time has been included in the allowances in arc welding cost chart—Table IV.

Line-Up after Welding—The amount of line-up needed after arc welding is very little in comparison to that needed after other method. In both cases, this time has been included in the allowances.

Additional Potential Savings—In the present report, all comparisons were made with similar design. Actually, since arc welding can successfully utilize welding electrode with greater strength of deposited metal, re-design of parts now used for the other method of welding may result in weight saving, with additional saving of time and cost. The advantages of arc welding for new designs is also evident.

Concluding Comments—The engine mount unit analyzed in this paper was selected because it could be arc welded without redesign, consequently permitting a very exact comparison with the other method of welding.

The use of arc welding simplifies process control in that time standards can be more accurately predicted and maintained. For example, an other-method welder can puddle the weld or otherwise rework it, which requires additional time and gives a misleading impression of a better weld than an

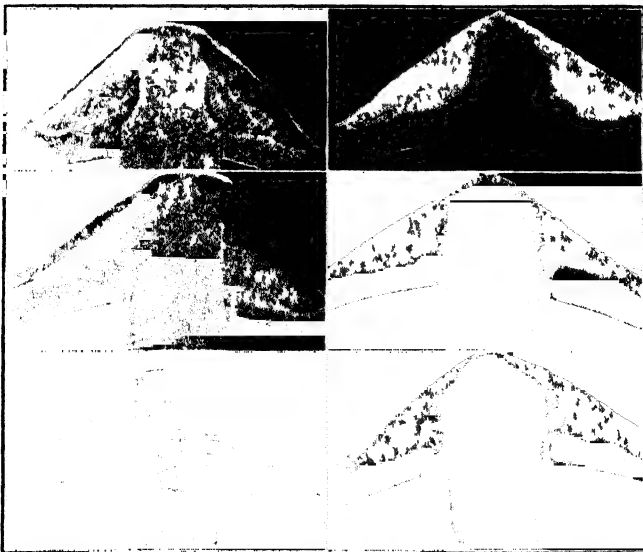



Fig. 5. Cross sections of welds, tube and forging of engine mount, arc welded (left), other-method welded (right).

arc weld based on appearance. In addition, although not mentioned in the paper, it has been possible to arc weld heat treated tubes and fittings without the need for subsequent heat treatment after welding. Arc welding anneals the adjacent material less than the other method.

Arc welding produces less oxidation of the areas being welded, which condition suggests that the subject for future investigation should be that of determining the deoxidizing and decarburizing effects of various types of welding.

In conclusion it is stated that it is not sufficient to merely utilize an art but to advance it.

References

Procedures—1, Materials Laboratory Procedure 14—"Control of—Welding"; 2, Army Air Corp Specification—"Qualification Tests for Aircraft Welders (Steel Welders)"; 3, Navy Specification—"Welding Procedure for Certification of Welders."

Base Metals—4, Army-Navy Specification—"Steel; Chrome, Molybdenum (4140) Bar and Rod"; 5, Army-Navy Specification—"Tubing; Steel, Chrome, Molybdenum (X4130), Seamless."

Welding Rod—6, Air Corps Specification—"Wire; Iron and Steel, Welding (for Aeronautical Use)" Grade 1-G—Welding. Grades 1E-6E—Arc Welding.

Analysis—7, By local recognized laboratory.

Time Study and Costs—8, Company time study department; 9, Company purchasing department; 10, Chart of — and — Consumption of Styles 9800, 9900, 8800, 8900—

Equipment—11,—Welding—Company Standard—Vendor's data. Torch —style 9900; 12, Arc Welding—(a), Wilson "Hornet" Electric Arc Welder, 200 ampere D.C.; Wilson Welder & Metals Co. Inc., New York, N. Y.; (b), Lincoln "Shield-Arc Jr." Aircraft Welder, 200 ampere D.C.; Lincoln Electric Company, Cleveland, Ohio; (c), Westinghouse "Flexarc" A.C. Welder, 250 ampere; Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

Chapter II—Aircraft Propeller Blade

By DR. ELEK K. BENEDEK,
Consulting Engineer, General Hydraulic Co., Cleveland, Ohio.

Dr. Elek K. Benedek

Subject Matter: Propeller blade for aircraft. A novel design for a heavy-duty propeller which will consist of a frame of beams and profile plates welded together and covered with a thin skin.

INTRODUCTION

One of the most outstanding engineering problems of the aircraft industry, today, is the design of propeller blades for aircraft. The efficient transmission of huge horsepower such as 2000 horsepower per propeller, sets up new theoretical, as well as practical, requirements for the design. This is the reason that propellers made out of lighter-than-steel metals, such as aluminum or magnesium alloys will pass away as quickly as the wooden propellers did under the increasing demand of commercial expectations. Duraluminum and magnesium alloys, while they are very light, do not have the elastic stamina required for endurance. That the present solid aluminum alloy (lynite) propellers cannot fill the further requirements needed by larger craft is well recognized, and is publicized by outstanding propeller specialists. Whereas, by giving the proper shape to the cross section of the steel blade it can be kept light, still its elastic energy remains several times greater than that of the above lighter metals.

To alleviate the shortcomings of the conventional propellers, designers attempted to make the blades out of hollow steel, by the process of various kind of welding. Small and large blades were made of sheet metal by the process of welding, and were found very good in performance and endurance characteristics. These results were due primarily to the outstanding mechanical properties of the steel as structural material, and to the reliable technique of the welding processes used. The best material, such as high grade alloy steel, when subjected to the best method of fabrication gave the best results under the complexity of heavy-duty performance requirements.

Past practice and design of welded steel blades, however, did not solve all the problems of the rapidly growing aviation industry, particularly those which did not even exist until just a very short time ago.

This is the reason the writer turned to this most vital problem of propeller blade design, and on the basis of past experience he believes that the complete solution of the propeller design lies in the direction of welded steel blades and propellers. Light metals, such as duraluminum and magnesium are deferred

already for the same reason as the wood, namely, for lack of elastic stamina. Efficient design requires such production methods in which the best aerodynamic efficiency is not only incorporated, but in which it will be always duplicated.

Due to the possibility of uncontrollable mechanical and aerodynamical imperfection in conventional large blades, there are already so many vibrations in present hollow steel propellers, that even a classification of them is almost impossible.

It is the object of this paper to provide a more effective and simplified welded structure which will not only be better and stronger, but which will be more suited to production and control, and the elimination of the above defects and vibrations. It, also, will be shown that welding is the best method today which can produce this improved steel structure, and that arc welding is cheaper and commercially more available than other more specific and delicate welding methods.

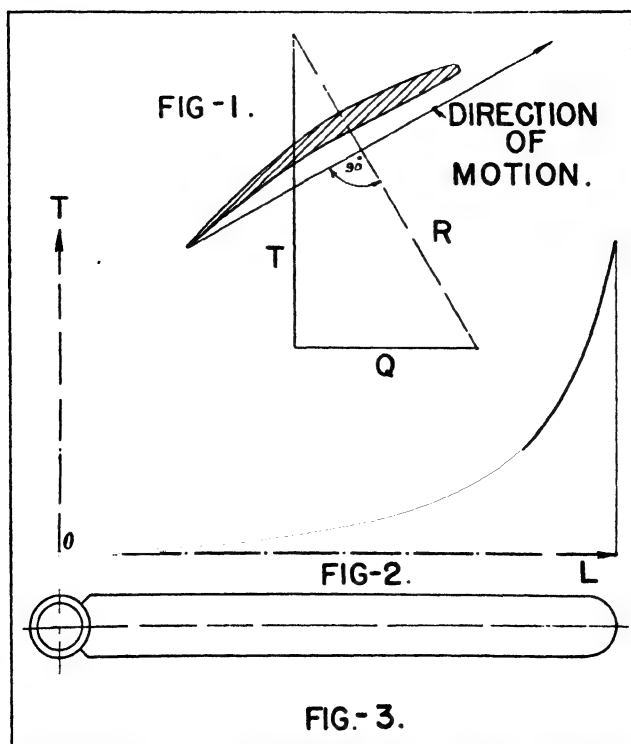



Fig. 1. Aero dynamical force "R" acts in direction normal to chord of profile. Figs. 2 and 3. Traction force rapidly increases toward tip of propeller.

Welded Constructions

(a) Welded Steel Propeller With Hollow Shank and Knife-Edge Blade.

Propeller blades are one of the most difficult machine elements to make in the aircraft industry today. This is due to the rigid expectation of the propeller mechanism, which is in itself a complete hydraulic motor which has to transmit the engine horsepower into the flight power, at the best possible efficiency.

Transatlantic flight diagnoses show that the commercial possibility of such flights often depends on the increase of one single percent in propeller efficiency.

Disregarding aerodynamical requirements, but remaining at the task of transmitting huge horsepower, such as 750 horsepower by one single blade, obviously requires the best that aircraft engineering can offer in all possible directions. Considering, also, that the inevitable method of blade mounting at the end of a cantilever crankshaft is given, it is evident that a multiplicity of rigid requirements and problems present themselves for solution right at the start, with the mounting.

Critical phenomena such as the flutter of the propeller is only a resonance between engine and propeller vibrations, but the forced vibration of the crankshaft is normal and it is carried over to the force vibration of the propeller blades. The thrust of each blade will impose a bending moment which is normal to the axis of the blade. The centrifugal force is the most critical. It acts axially on the normal section of the blade.

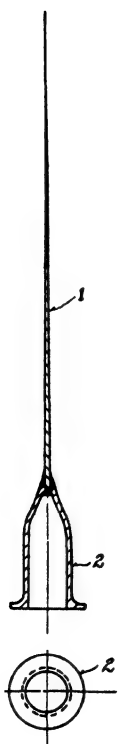
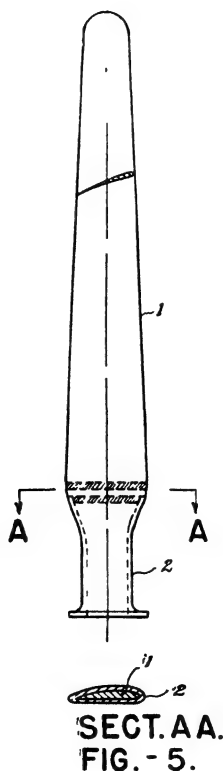
For the purpose of simplicity, the consideration of other imposed stresses and phenomena are omitted in this discussion now, but it is pointed out that the basic improvement of the present design has reduced or fully eliminated limitations and dangers in conventional propellers.

It is well known that the major portion of the length of a lynite propeller is so heavy that only a short portion toward the tip remains flexible. It is this flexible end, however, which breaks off and causes the principal danger of conventional lynite propellers. The poor mechanical properties of the aluminum alloy are only partly responsible for the above limitations, i.e., for the excessive weight of the blade, as well as for the breaking off of the tip. Other limitations are due to design factors. These limited factors bar the lynite blades, however, from further application as longer blades on larger aircraft; and there is no way of alleviating these factors in the conventional design.

Fig. 4, and Fig. 5, show a two-part welded steel propeller which eliminates the above basic defects of solid aluminum alloy propellers. The proper blade 1, is made of thin forged steel, and at its bottom, is arc welded to a hollow steel shank portion 2. This hollow steel portion is practically rigid, while the flexible or knife-edge portion is elastic. It is a knife-edge made of spring steel. The substance of this welded combination is that the forced vibration of the entire blade will have a nodal point at the point of the welded connection and, thus, the blade 1, will have its own free and smooth harmonic oscillation along its entire length. This vibration will be substantially different from the rigid forced vibration of the shank portion 2. The vibration of the entire blade will relieve the tip as well as any other portion of the spring blade from concentrated vibrations and tip breakage. Part 2 is preferably made out of rigid seamless steel tubing of suitable material. It is formed to the proper shape to receive the end of blade 1, and mounted safely against the maximum load.

The welded mounting can be achieved by conventional arc welding, preferably at two zones, such as shown in Fig. 4, and Fig. 5. The inside and outside welds are both readily accessible for final finish since the shank is hollow and will be polished to the proper smoothness. The necessary heat treatment of the welds and the tempering of the spring blade, 1, will complete the process. It can be stated already that there is no chance of the breaking off of the blades at the walled-in and welded end. The good properties of the spring steel and tubing provide all necessary resistance to this welded joint.

Simultaneously, the refined aerodynamical profile throughout the entire length will improve the hydraulic efficiency together with the traction of the

propeller as shown in Fig. 2. This figure shows that the traction force is rapidly increasing toward the tip of the propeller. See, also, Fig. 3. Thus, it is obvious that the curve of the knife-edge blade will have a quicker pick-up toward the tip than the curve of the clumsy solid aluminum alloy propeller. This propeller supersedes also, in weight, the solid aluminum alloy propeller, which is an important design consideration. Due to the outstanding properties of the different steel portion, the shape can be made such that the blade stability as well as its radial strength will meet any necessary requirement at a minimum expense of weight. This better streamlined profile will adapt the blade, also, for higher engine speeds without the necessity of using reduction of gearing.

Figs. 4 and 5. Two-part welded steel propeller which eliminates basic defects of solid aluminum type.

It is admitted that the welding process occupies only a very small space in the entire manufacture of this blade, but that much greater is its importance; and it has no substitute.

The danger of mistreatment of the parts by the method of conventional arc welding is very small, since all necessary details may be obtained readily from welding specialists.

Arc welding achieves the simplest, cheapest, and strongest connection between the two parts, 1, and 2. The fact that the two parts, 1, and 2, may be manufactured separately and finished independently from each other, prior

to the welding is important from the savings and production point of view. It reduces the cost of necessary machine tools, operations, jigs and fixtures, as compared with the cost of manufacture of the one-piece blade. The entire blade, with the welded joint, can be polished internally and externally after the welding. The danger of tip break-off is entirely eliminated and the low pitch vibration of the blade quiets the entire performance of the power plant, and the plane, respectively.

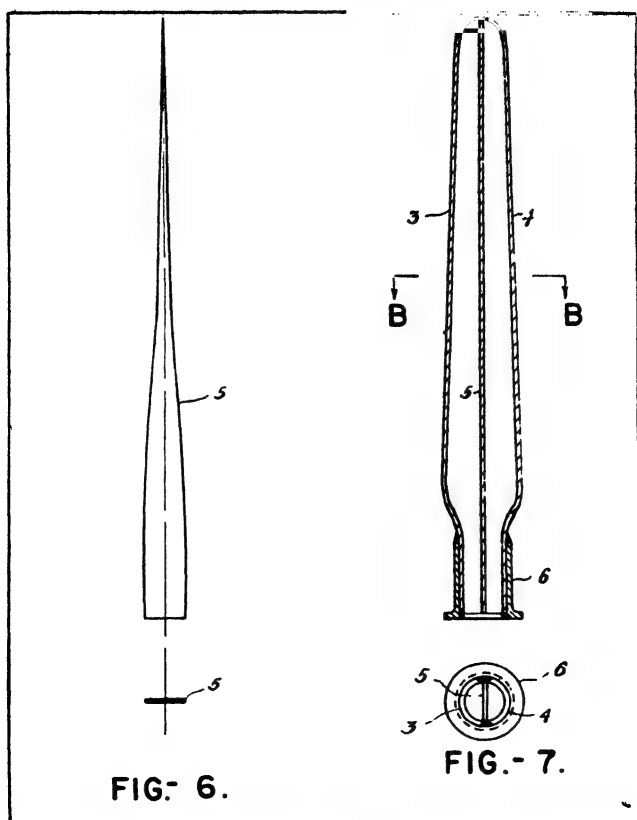
The above method of fabrication is also applicable with proper changes and modification to non-ferrous alloy propellers. While the conventional blade carries a long and heavy inefficient shank, with a short fluttering, inefficient tip, the present design embodies a light, hollow short shank, and carries an elastic, long blade, which is efficient throughout its entire length. It will be seen, also, that the arc welding, with selected simplified material and design, eliminates all scrap from the manufacture of the propeller blade, and thus it greatly reduces its cost through the saving in labor and material.

(b) Welded Steel Propeller Blade of the Rigid Skin and Reinforced Structural Steel Type.

Some of the present-day conventional hollow-steel propellers have reached considerable success. However, close consideration shows that the large blades, particularly, need considerably further improvement.

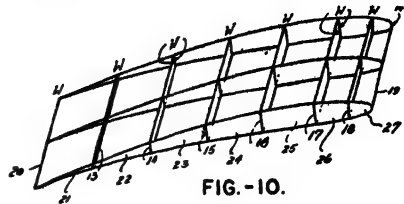
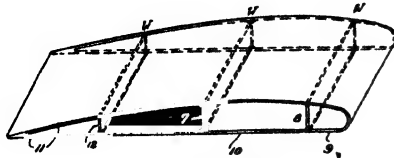
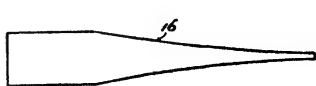
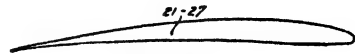
One of the reasons for the limitations of the entirely hollow, conventional steel propellers, lies in the weakness of their design as will be clear from Fig. 1. This figure shows that the resultant aerodynamical force R, of each propeller element acts in a direction substantially normal to the chord of the profile. Since the design of the conventional hollow steel propellers provides no direct strength or reinforcement in the normal direction, the material of the hollow section becomes weakened under the vibration stresses, and the section will burst.

The present design, shown in Fig. 6, and Fig. 7, does not only alleviate this weakness, but readily improves the blade, by adding in the critical section of the profile a simple reinforcing member as at 5, in Fig. 6, and Fig. 7. This reinforcing member 5, passes throughout the entire length of the section, and places in the direction of the resultant aerodynamic load R, the necessary reinforcement. With its height and major moment of inertia in this direction, it will withstand and resist all loads and vibrations in this direction. At the same time, it brings into reinforced coaction the suction and the pressure side of the profile of the blade. This reinforcing coaction greatly increases the transverse strength and stability of the blade, and it qualifies the structure for more severe applications than known heretofore. A substantial weight reduction is also obtained for the same reason.

The reinforcing member, 5, thus does not only add its own structural strength to the strength of the profiles, but it eliminates transverse vibrations of the suction and pressure profiles with respect to each other under the resultant load R. This latter vibration is often called the breathing of the propeller. Its negative effect is the early failure of the material, and the reduction of hydraulic efficiency of the blade. Evidently a vibratory profile has a worse circulation than a stable, positive, profile. Further, the reinforcing section produces a gain in hydraulic efficiency by way of better profile. When no reinforcing is provided in the hollow profile a heavier wall section automatically becomes necessary. But reinforced with a longitudinal beam as at 5, gives the design a better streamlined profile. From the above consideration, it is obvious that this structure has a greater resistance to both torsional and centrifugal force vibration stresses, and will stand greater rotary speed.

Figs. 6 and 7. Simple reinforcing member added in critical section.

A more-than-two-compartment-profile design is shown in Fig. 9. Here are provided three beams, 7, 8, and 12, respectively, which divide the profile into four compartments. This design is provided for larger propellers where further reduction in weight, and gain in strength and rotary speed are imperative.

As for the welding technique of such propellers, it will be seen that, for instance, the central beam 7, is welded first to the top and then to the bottom of plates 10-10, respectively, whereupon, the front and rear beam 8, and 12, respectively, will be welded to the edges of the top and bottom plates 10-10, respectively. Thus, it is forming, so far, two closed compartments. The leading end 2, and trailing end 11, of the section thus will be welded along the edges of the top and bottom plates 10-10, respectively, of the central compartments and beams 8, and 12, respectively. It will be noted that this structure, while it provides simple means to comply with the rigid requirements of good efficiency and perfect geometry of the profile, it gives, also, greater rigidity and strength at reduced weight per horsepower ratio.

In the foregoing designs the profile plates 9, and 10, and 11, are contributing substantially to the strength of the blade, since they are heavy and in welded rigid coaction with the axially extending longitudinal beams 7, 8, and 12, thus forming part of the whole strength structure. In the following modifi-

Figs. 8 and 9, (left). Design of more than 2-compartment profile. Figs. 10, 11, 12 and 13, (right). Novel blade structure is improved streamlined for light-weight propeller of larger sizes.

cations, the strength structure will be separated from the skin plates or airfoil structure.

(c) Welded Steel Blade of the Elastic Skin and Complete Structural Steel Body Type.

Fig. 10, to Fig. 13, show a novel blade structure for improved streamlined and light-weight propellers of the larger sizes. The combination comprises axially extending beams 13, to 20, properly spaced and positioned in such a manner that they give lateral strength and resistance against thrust, centrifugal and torsional forces, and, at the same time, provide the proper form for an airfoil section as in Fig. 11, and 12.

At the shank, as in Fig. 12, the beams will be disposed in a similar way, inside a longitudinal straight cylinder. Further sections, as in Fig. 10, the profile plates 21, to 27, will be carefully formed and positioned to determine and fix the final relative position of the axial beams 13, to 20. The profile plates may be made by stamping as in Fig. 13, and sawed to sub-sections to fit between the longitudinal beams 13, to 20, as in Fig. 10. Appropriate welding fixtures will enable the welding as at W. It will be noted that the beams 13, to 20, are the main longitudinal stress members and they remain integral longitudinally, as in Fig. 11, to Fig. 12. The great advantage of the use of the stamped airfoil profiles, as in Fig. 13, is that they can be preset in their theoretical position by means of simple welding fixtures, and then be sawed into individual pieces prior to the final welding assembly, as in Fig. 10.

Each adjacent beam and profile plate, respectively, thus forms a plurality of cells which are yet open from the top and from the bottom, but will be closed by the skin. The skin may be wrapped around the strength structure, or pulled over on it, in stressed position from the shank end toward the blade. A two-part skin may be welded to the top and bottom of the strength structure along the longitudinal beams 19, and 20, respectively. The shank portion of the blades may be formed and finished as in Fig. 7, embodying the geometry of Fig. 12. This design lends itself to very accurate profile control, and easy checking up of the pitch of the blade, particularly in aerodynamical respects. The skin may be made renewable, as primarily it is only a coverage, resting tightly against the beams and profile plates, and withstanding the vacuum and dynamic

pressure of the airflow. Since both the suction and the pressure are less than one atmosphere, it is obvious that very thin sheet metal skin will perform this pressure duty. Breathing of the profile is thus eliminated, and considerable weight reduction is obtained. The repair of the blade, due to skin disease becomes easy and effective by either exchanging, or patching up the damage. The new elements, 21, to 27, increase torsional rigidity and transverse stiffness of the blade, since they reinforce the beams, 13, to 20, as did beam 5, on the profile plates 3, and 4, in Fig. 7.

The facts that standard material of good alloy steel, and standard welding process, such as arc welding, may be used in the production of propellers increase productive capacity and possibilities of the Aircraft Industry, and provide the large aircraft with efficient and safe propellers. Due to the simplified structure in this latter case, expensive dies are eliminated, heat treating processes greatly reduced or eliminated, greater finished values are produced, and further design changes at less expense are made possible.

Factors of Judgment

(a) Proportionate Cost Savings per Unit Blade by Arc Welding of Type II (b) and II (c), respectively.

Type II(b) and II(c) propellers may be compared with other propellers.

Hollow steel types are made out of rigid skin, which is the strength-giving structure, and profile element of the blade. In this design, the forming of the profile is extremely difficult and warpage during heat treatment results in aerodynamic defects and unbalance of the blades. Aerodynamic unbalance means small profile irregularities which cannot be controlled by the process due to the insufficient nature of the design. Resistance welding is now used in the Aero Product, propellers. This propeller is entirely hollow, since rib 5, is missing. (See Fig. 7.)

The elimination of this deficiency by the new design permits a much lighter skin than the skin of the Aero Product design propeller. Also, due to the same reason, namely, the lack of reinforcement 5, the heat treatment of above propeller is very difficult, and results in substantial warpage. Too much checking and a great number of expensive control dies, jigs and fixtures, and repetitions, are necessary. The thinner skin in the present design reduces die work, necessitates smaller presses, etc., since it is much simpler to form the thinner sheets to the proper profile. Hydrogen weld really is less adaptable to thinner sheets as it is difficult to control the welding at higher temperatures. Arc welding is controlled easier, and without skilled labor, furnishes repetitive results at lower cost.

The brief outline of the main reasons for savings, as above, with design II(b), and II(c), clearly shows that while the total amount of weld, as one factor of the cost is practically the same in all of the designs, the immediate effect of rib 5, simplifies and controls positively the proper airfoil shape of the structure. It will be seen, also, that next to weight reduction, the proper shape is the most important factor in the production. Thus both weight and shape are greatly improved by the introduction of the rib element, 5. The main items of savings are as follows:

(1) Savings in cost of material (thinner plates, less welding rods, etc.) .... 5% min.
(2) Savings in jigs and fixtures .... 10% min.
(3) Savings in labor .... 12% min.

TOTAL 27% min.

Thus, the total relative savings figures from item (1), plus (2), plus (3), to a total of 27 per cent minimum. Estimated savings are more than twice the relative savings. Cost of the jigs and fixtures will be distributed throughout a complete production period. First cost of two six-foot long blades was $215 each. Propeller II(a), two-part, knife-edge steel blade is new, and the first cost of two six feet blades was $250 each, without dies and fixtures.

(b) Estimated Total Annual Gross Cost Savings Accruing From Arc Welding.

1. The use of arc welding by the company in supplying its present orders of propellers in this novel arc welded design saves $5,000,000, in three-and-two-blade propellers, in figuring 25 per cent net savings for all size blades, and a cost of $150 net for each single blade, large or small.

2. The use of arc welding by the American aviation industry as per the present design will save about $50,000,000 per annum, at the need of past peace time conditions.

Remarks: The cost of competitive conventional propellers to which this paper made reference was obtained as close as possible from material obtained from scientific publications, as herein referred to. Due to the rapid progress of the use of the arc welding process, more favorable figures are expected in this field.

(c) Outstanding New Results and Social Advantages of Arc Welding.

The solution of the above problems by new design and arc welding undoubtedly will produce such far-reaching changes and advantages in national security and economy, that they will affect the future life of every citizen. It will bring about a safer life, and sustain a better civilization. The quicker these new designs and methods are put into effect the sooner economic stresses will decrease, and human sufferings and misery will stop. It is hoped that the above research will, also, stimulate better and further research, and contribute to the structure of a better world and scientific civilization.

Forward with the light of the process of arc welding!

Chapter III—Redesign of Airplane Engine Tail Pipe

By MARTIN BULGER,

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Martin Bulger

Subject Matter: The author has redesigned the tail pipe to improve its strength and, thereby, eliminate the large waste incurred as a result of discarding the tail pipes when worn through at one end from motor vibration. The tail pipe is the section leading from the exhaust collector manifold and carries off the exhaust gases. The pipe is made of stainless steel. By adding strips of stainless steel to the mounting lip of the pipe, the author doubles the strength and thickness of the vibrating point and increases the life expectancy of the pipe. This addition is accomplished by means of arc welding at a total cost of $1.50 and would result in the saving of 50 per cent of the pipes necessary.

This present era in world history, with its full and absolute demands on time, manpower and materials, must of necessity bring about a change in values and the methods of appraising these values. In my opinion, time and the elimination of waste are the deciding and prevailing factors in our struggle to survive. It was with that thought in mind that the problem of the redesign of the tail pipe of the "G-102" airplane engine was approached.

This particular innovation can be accomplished only by arc welding. Another method of welding would be completely impracticable, causing the pipe to warp and crack, and be unfit for any further use.

The tail pipe, (See Figs. 1 and 2), is that particular section of the exhaust system, which leads from the exhaust collector manifold and carries off the exhaust gases. Due to the constant vibration, the collars connecting the tail pipe to the engine exhaust collector manifold, have a life expectancy of approximately 6000 hours. It has been the custom in the industry to remove, dispose of and replace this entire tail pipe section. The price per unit cost is $91.50, with labor approaching four hours each for two men.

This tail pipe is composed of stainless steel about 52 inches long and 9 inches in dameter. The collar section is connected by three one-inch lugs, breaking the exterior circumference into three six-inch sections. It is these particular sections that are affected by the motor vibrations and wear thin, causing the removal and replacement, with the entire tail pipe going into the scrap heap. This means an annual consumption by average airlines of about 40 tail pipes a year, and by the industry as a whole of a conservative 175 at a total cost of $15,912.50 or roughly $16,000 plus the cost of 1400 man hours of labor necessary for the installation.

By actual test, I have been able to redesign the unit as it leaves the factory to add 100 per cent longer life, and to effect repairs on present units to double their wear.

This redesign is accomplished by arc welding as follows: Lay out three pieces of stainless steel sheet, 2 inches by 6 inches by 18-gauge. Divide each strip into four equal parts. Starting at a point $\frac{3}{16}$-inch below the lower or

Fig. 1, (left). Subject of study. Fig. 2, (right). Close-up of welds in tail pipe.

inner lip, the part that will go on the collector manifold, cut an inverted V whose base is ⅜-inch wide. This inverted V will take up the difference between the outer and inner section of the collar which is bell-shaped in design. These three sections of stainless steel are tacked on to the original collar then welded. This doubles the thickness and strength of the vibrating point and increases life expectancy by the same ratio.

The three strips of steel cost 10 cents each. The welding rod is 25 cents and the time necessary to complete the job is slightly less than one hour. Total cost $1.50. Total saving for the industry is a 50 per cent reduction in the number of pipes necessary, a saving of the 1400 man hours for the installation on the new pipes at the end of the 6000 hours of use. Each pipe weighs 23 pounds or a saving of a ton a year.

The data assembled in the preceding paragraphs pertain only to the tail pipe, which was the principal concern of this author when effecting his original innovation. There are, however, two additional sections, namely, the bell section and the expansion joint which are similarly affected, require almost as much time and labor, cost as much to install, but whose cost totals about half the exhaust pipe cost.

In actual practice, it will be found that these figures of costs and savings are most conservative. It must be remembered that after the cessation of hostilities, an air-minded public will demand much more service, many more planes, more flying hours, and a proportionate increase in the demands for materials which will effect an even greater savings.

Chapter IV—Arc Welding of Magnesium Aircraft Structures

By Vladimir H. Pavlecka and John K. Northrop,
Chief of Research and President, respectively,
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Vladimir H. Pavlecka

Subject Matter: The research work described has resulted in the development of a successful method of arc welding magnesium alloys in aircraft construction A tungsten electrode is used in a stream of helium. Additional weld metal is fed from an uncoated electrode The paper describes the design and fabrication of wings of "monocoque" type from magnesium alloy, for trainer planes

John K. Northrop

Monocoque Aircraft Structures—During the last decade, monocoque, or semi-monocoque aircraft structures, in which all, or a substantial portion of the structure load, is carried in the skin, have come into general favor among airplane designers A survey of modern aircraft finds few, if any, planes in which wings, fuselage, or tail structures are not substantially based on the stressed-skin principle, and many modern airplanes are almost solely dependent upon this principle for their long service life and rugged structural integrity.

Pioneered more than 25 years ago, the airplane fuselage fabricated from glued and nailed wooden strips was the first element in which the stressed-skin principle was used widely with success. Beginning within the last 15 years the same ideas have been applied with great advantage to steel, aluminum, and magnesium parts, while the newer synthetic binding resins have been utilized with excellent effect to improve the wood-base structures of the pioneers of monocoque.

The best and most efficient materials for use in pure monocoque construction are unquestionably those having low specific gravity and relatively high modulus of elasticity, in order that the material may have high compressive strength before buckling occurs On this basis, certain plywood combinations, if uniform in quality and readily available in quantity, would no doubt prove of best structural value.

Unfortunately, however, nature controls the quality of tree growth, and the quantity is very severely limited by the number of suitable trees already in existence at a time of emergency. Those with sufficient summers to remember World War I can vividly recollect the shortage of suitable airplane lumber, and the resultant skyrocketing prices thereof, even as a result of the comparatively insignificant aircraft production of that day, and it is thought that even the most enthusiastic proponents of "plastic" (plywood) planes do not recommend their processes as applicable to more than a small portion of the present aircraft program.

On the other hand, metals are available (though rationed as to use) in

very much larger quantities. Their qualities can be kept exceedingly uniform by comparison with those of a grove of trees, and production increases are dependent solely on men's energies and ingenuities.

Stressed Skin Metal Aircraft Structures—These facts led the authors, early in 1940, to choose the field of metals in a research program directed toward obtaining more efficient stressed-skin aircraft structures. While it was realized that the miracle of the organic chemist's test tube might one day produce a "true" plastic of outstanding physical qualities, nevertheless, the need was immediate, and there were available at hand metallic alloys having great promise.

In metals, as in other substances, low specific gravity in combination with high modulus of elasticity offered the most attractive field of research. Stressed-skin structures of steel have been commonplace in other fields of endeavor, but when designed to weight limits acceptable for modern aircraft, the result was almost always a comparatively thin sheet operating within its buckling range, and "stiffened" by a multitude of small formed beams, ribs, or stringers, spot welded or riveted to the main cover sheet. Here the cost of forming, handling, tooling and assembling becomes a serious if not prohibitive factor, although very efficient steel structures of a semi-monocoque type have been designed and built.

As the best known and most widely developed of the so-called light metals, aluminum and its alloys have come to be almost universally used for most external aircraft coverings.

Pioneered in European countries, at first largely to carry shear and torque loads as a wing and fuselage covering, aluminum has become within the last ten years an indispensable and major element in the designer's field of materials, and is used, reinforced by strips, extrusions, beads, or ribs, for the major portion of the structure on most military and transport aircraft that fly today. In the earliest examples, aluminum was used in corrugated form in an effort to increase the effective thickness, while later, smoother surfaces were demanded to reduce the excessive drag always related to external corrugated skin.

Flat aluminum sheet, however, must be regarded as having a higher density than desirable, and is rarely used without some internal stiffening strips or corrugations. Likewise, the comparatively thin cover sheets buckle within the range of normal-flight loads, as can readily be seen during a short ride in a modern transport. Also, while spot welding has been developed to an excellent degree of reliability for many of the aluminum alloys, an exacting technique is required in its use, and many joints must be made where the physical limits of spot welding equipment do not permit its use.

And so we find most modern aircraft to contain from 100,000 to over a million rivets, each requiring a layout, at least one and often two punching or drilling operations, and, in a majority of cases, the attention of two operators to drive. Then comes an individual inspection of each rivet which, if not successful, requires replacement and the expense and delays attendant thereon.

A further stimulus to the search for better, cheaper, and smoother aircraft structures lies in the fact that great advances in the science of aerodynamics have proven conclusively that the effects of rivet heads, (even if countersunk), local buckling, and general surface irregularities are much more detrimental than previously believed, and that the aerodynamic form of the external surface must be smooth, uniformly finished, and without local buckles if minimum drag is to be achieved.

Magnesium Alloys—All of the above consideration led, early in 1940, to a further investigation of available materials and methods of fabrication. As the lightest of generally available structural materials, magnesium and its alloys soon proved most attractive. Less than two-thirds of the weight of aluminum, and not much over one-fifth as heavy as steel, such materials have a relative stiffness, for a given weight of 2.5 times that of aluminum and 19.5 times that of steel.

First developed in the United States by the Dow Chemical Company as a relatively useless by-product, Dowmetal alloys have recently assumed greater and greater importance in the manufacture of aircraft. Available in cast, extruded, forged, and rolled form, these materials have first been used largely in engines, wheels, other accessories and secondary structures rather than in primary parts, although usage in Germany (where the comparatively greater availability has rendered magnesium especially attractive) has been more widespread than in the United States. The facts that the production of magnesium is rapidly expanding, that the sources are inexhaustible (9,000,000,000 pounds in each cubic mile of sea water), and that next to beryllium it is theoretically the best possible material for simple metal monocoque structures, have assured its widespread use in aircraft.

Research on Fabrication—Once a decision was reached as to the material choice, attention was at once turned to methods of fabrication. Magnesium had previously been spot welded and gas welded successfully. However, rivets of magnesium alloy work-hardened so rapidly during driving as to prove impractical, so that other materials had to be used for rivets in the assembly of magnesium parts. Also, the ideal surface smoothness for which we have been striving
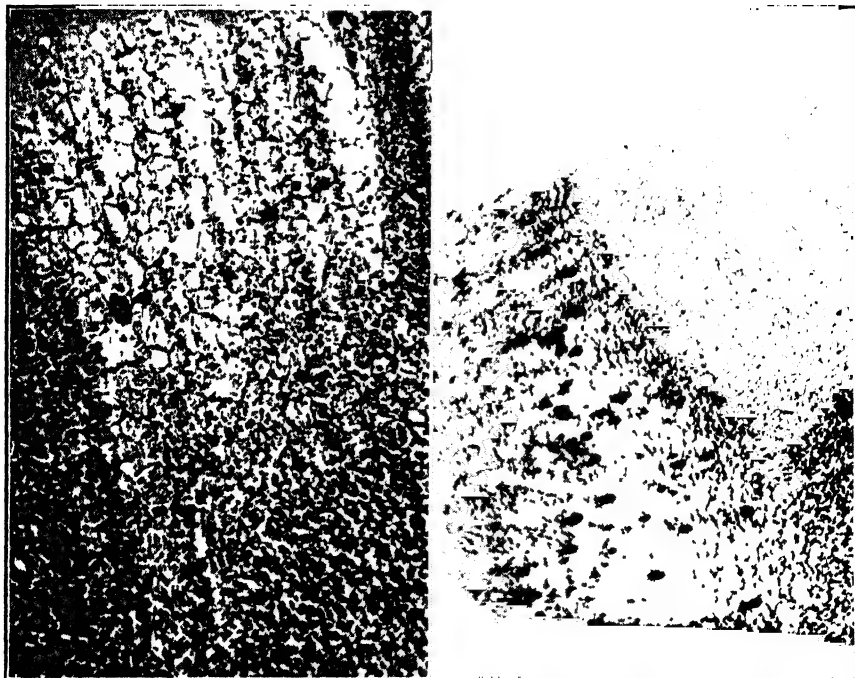
Fig. 1. Magnesium alloy arc welded. Left: Parent metal at top and weld metal at bottom. Right: Parent metal at left, weld metal at right.

cannot be obtained by lap-joints, whether riveted or spot welded, particularly in view of the comparatively thick sheets which are employed in pure monocoque design. Gas welding was available as a means of attachment, but gas welding could only be accomplished under the protection of a heavy flux, due to the extreme affinity of magnesium for oxygen and nitrogen, particularly at elevated temperatures. And, unfortunately, the successful fluxes available were all of an extremely corrosive nature, and rapidly attacked the resultant magnesium assembly if the slightest contamination remained in the weld.

After many disheartening attempts, the path of research led finally to the consideration of electric arc welding which had previously been considered impossible on magnesium. The first experiments led to many small-magnesium fires. An amazing number of preliminary experiments can be imagined, when all possible variations in alternating and direct currents, polarity, types and materials for electrodes, fluxes, and blanketing gases were tried. It is the belief of the authors that all the unsuccessful combinations were attempted not once but many times. Fluxes were soon abandoned from considerations of corrosion, and numerous efforts were made to weld, using various types of blanketing gases either in an enclosed space, or allowed to flow over the work from the vicinity of the electrode. The first glimmerings of success occurred when the arc was struck between the work and a magnesium electrode which was supported in a hollow receptacle through which helium, under low pressure, was allowed to flow into the weld area. With this arrangement, however, the control of the flow of material to the weld was erratic and blobs of the electrode appeared in a disheartening array along the weld. Various refractory materials were then tried for the electrode, and when the research program reached the stage where a tungsten electrode was used in a helium atmosphere, success instantly crowned more than a year of experimentation and the "Heliarc" method of welding was born.

Electric Arc Welding of Magnesium—Basically, this method of electric welding, useful with all standard direct-current welding machines. consists in striking an arc between the work and a tungsten electrode, simultaneously feeding helium gas to the weld area through an annular nozzle surrounding the electrode, and feeding the additional weld material needed for the joint into the arc from an uncoated welding rod of substantially the same material as the work. Reversed polarity is used, that is, the current flows from the work to the electrode. The flow of helium, fed to the work area at .25 to .5 pounds per square inch, is controlled by a valve on the torch handle which is opened by the operator just before the arc is struck, and held open during the welding process. The arc is very quiet during a "Heliarc" weld, there is no tendency to sputter or throw materials from the weld as is sometimes the case with other processes, and a very uniform, high-quality weld can be obtained by an average operator after short practice. This method of welding will shortly be made available to the public under license, and while it was developed primarily for use on magnesium, it will probably find extensive use on alloy and stainless steels, where the results seem superior to those obtained by any other known method. The quality of the weld is high, the strength of the joint varying from 80 to over 100 per cent of the parent material, depending on the alloy and welding conditions, and there seems to be no limitation in the type of joint that can be made—butt, lap, tee, corner, and angle joints being made with equal facility.

The helium blanket completely eliminates the use of any flux in the joint, and while minute quantities of tungsten are present in the joint, there are no adverse corrosive effects therefrom. Actually, the weld appears somewhat

more corrosion-resistant than the parent metal, there being a slight electrolytic balance which causes corrosion, if it appears at all, to be present in the sheet adjacent to the weld rather than in the weld itself. This effect is so small, however, as to be negligible for all practical purposes. Welds can be made with equal facility in rolled, cast, extruded, or forged parts, and some experiments have been made where cast and rolled or extruded parts have been welded to each other.

The seams, fusion welded by the "Heliarc" process, are distinguished by their metallurgical purity, homogeneity, and absence of inclusions. Fig. 1 shows a typical microscopic view of an etched "Heliarc"-welded seam in Dowmetal J-1 magnesium alloy. From it will be apparent the close-grained, highly-packed fused metal, which has approximately two per cent higher density than the parent metal, acquired in the welding process. It will be particularly noted that the fusion boundary is gradual and deeply penerating.

A typical torch assembly is shown in Fig. 2. Any good DC welding equipment is suitable for use in the "Heliarc" method, and the process has a particular attraction and importance in the United States, since our country is today the sole producer of this gas on a commercial scale and in large quantities, and also because considerable reserve volumes of it have been accumulated in the last six years.
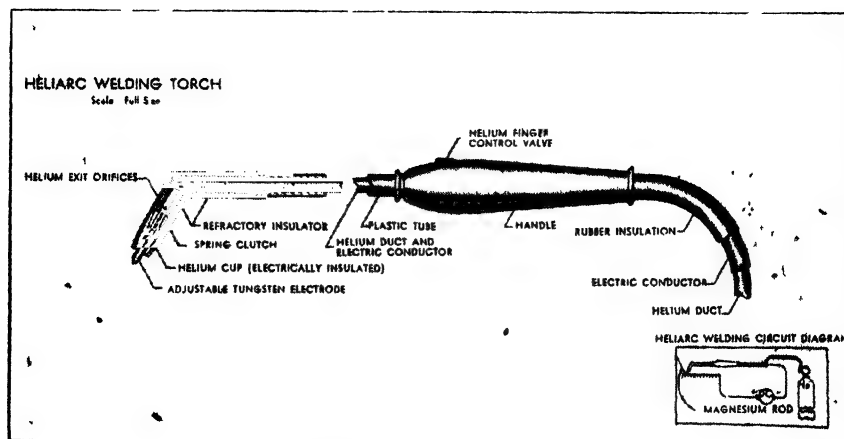
Fig. 2. Heliarc welding torch.

Design Considerations—Shortly after the first successful "Heliarc" welds were made a large number of samples were submitted to the Army Air Forces Material Center, for test and inspection. Complete checks, including fatigue tests, were made and the weld qualities appeared amply good to warrant an immediate program whereby a primary aircraft structure, assembled of magnesium alloys by electric arc welding, would be built. As a result, a contract for a number of airplane wings for Army Air Forces BC-1 trainer airplanes was given to this company early in 1941, and the design and development of these wings was begun at once, using Dowmetal J1-H alloy.

It was reasoned that the application of magnesium alloys to aircraft construction could be accomplished along two different principles. The first and most obvious way would be to design a magnesium airplane structure for maximum weight reduction. This conception was studied with the conclusion that the undesirable physical properties of magnesium alloys (rapid strain

hardening, corrosion, etc.) would probably not permit a greater weight saving than approximately 10 per cent over a comparable structure made of aluminum alloy. In view of the established fact that only approximately one-third of the weight of a modern military airplane empty is the airframe, or structural, weight, the total weight saving would, at best, amount to some 3.5 per cent of the empty weight of the airplane.

This slight gain was judged to be overbalanced by the necessity of an extremely careful and expensive design which would require the use of relatively thin gages of magnesium alloy sheet. It was therefore decided to favor, in the design of these wings, the perfection of the aerodynamic shape and simplicity and low cost of structural construction. These two qualities, in the estimation of the authors, are more important than small weight savings, provided they can be gained without increase of commonly accepted structural weights.

The design criterion adopted was, therefore, that superior and less costly magnesium airplane structures could be designed and built for the same weight as the present more expensive aluminum alloy riveted structures. The resulting design is shown in diagrams, Fig. 3 and Fig. 4.

Design Applications—The wing design illustrated was not made analytically by taking the weight of the present BC-1 aluminum alloy riveted wing and reapportioning it to the various structural components of the magnesium alloy wing. On the contrary, the "Heliarc" welded magnesium alloy wings were designed synthetically from the test experience and data already accumulated, and from the calculated loads acting on the wing. These considerations determined the proportions and distributions of the structural component parts and also the type of welding seams to be used in connecting them.

The calculated loads were based on the same design factors as used in the design of the riveted aluminum alloy wings already in service on BC-1 airplanes. Before the construction of the wings was begun, a very detailed weight analysis was made which indicated that the weight of the completed welded magnesium alloy wing structures should be approximately the same as that of the aluminum riveted wings. This has been approximately confirmed by actual weighing of the finished structures.

The BC-1 welded wings are designed on the semi-monocoque principle, with an internal structure, mainly for the purpose of maintaining form. The principal stresses, due to bending and shear, are carried directly in the thick, non-buckling outer shell. The guiding design idea of structural simplicity was carried out to the extreme and it can be safely stated that there is hardly a part in the structure of the welded wings which does not directly carry a portion of the flight load.

Structural Details—The whole wing structure is composed of only two basic elements: the sheet, forming the monocoque shell, and extruded sections, forming the internal structure. The versatility of arc welded construction made it possible to limit the number of various extrusions, such as "tees", angles, etc., to no more than four different sections. Furthermore, the preparation of the profile sections and sheets was greatly simplified, because flanges for riveting, and elaborate templates for the shaping of parts and the coordination of multitudes of rivet holes, were no longer necessary.

In order to provide ready access for inspection and repair, the wing was subdivided into two principal caissons by a span-wise, quickly-detachable grip joint on the upper and lower surfaces of the wing. This joint facilitates assembly and servicing, the latter being particularly important in a military
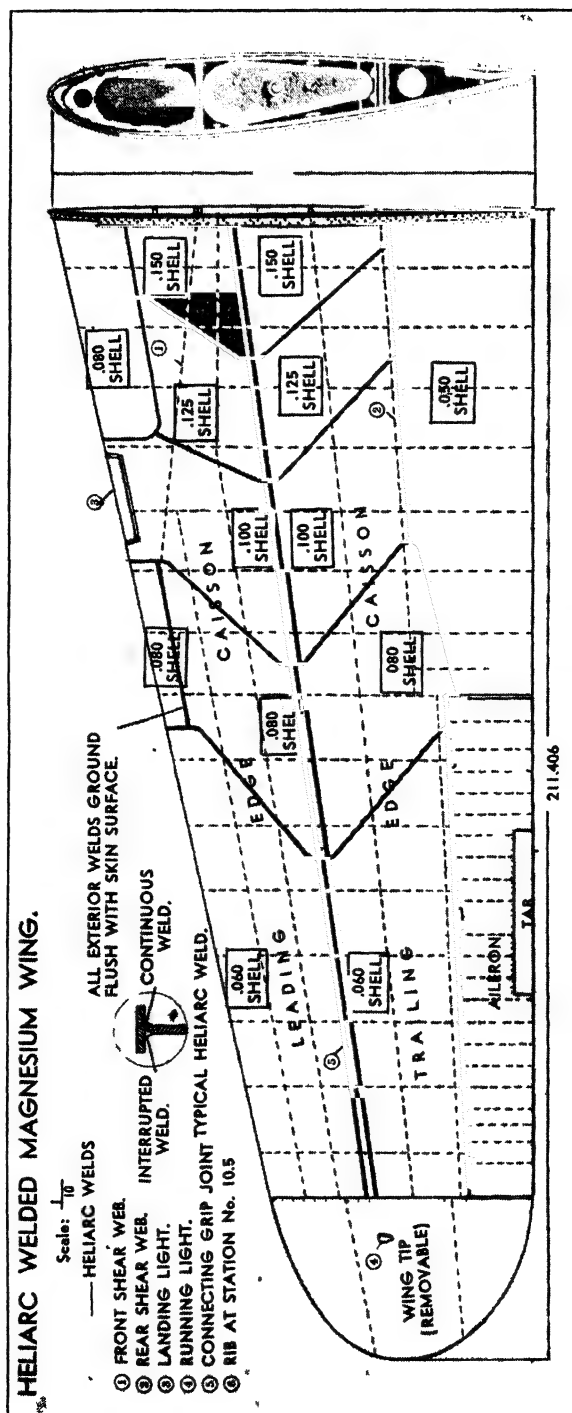
Fig. 3. Welded magnesium wing (top surface).
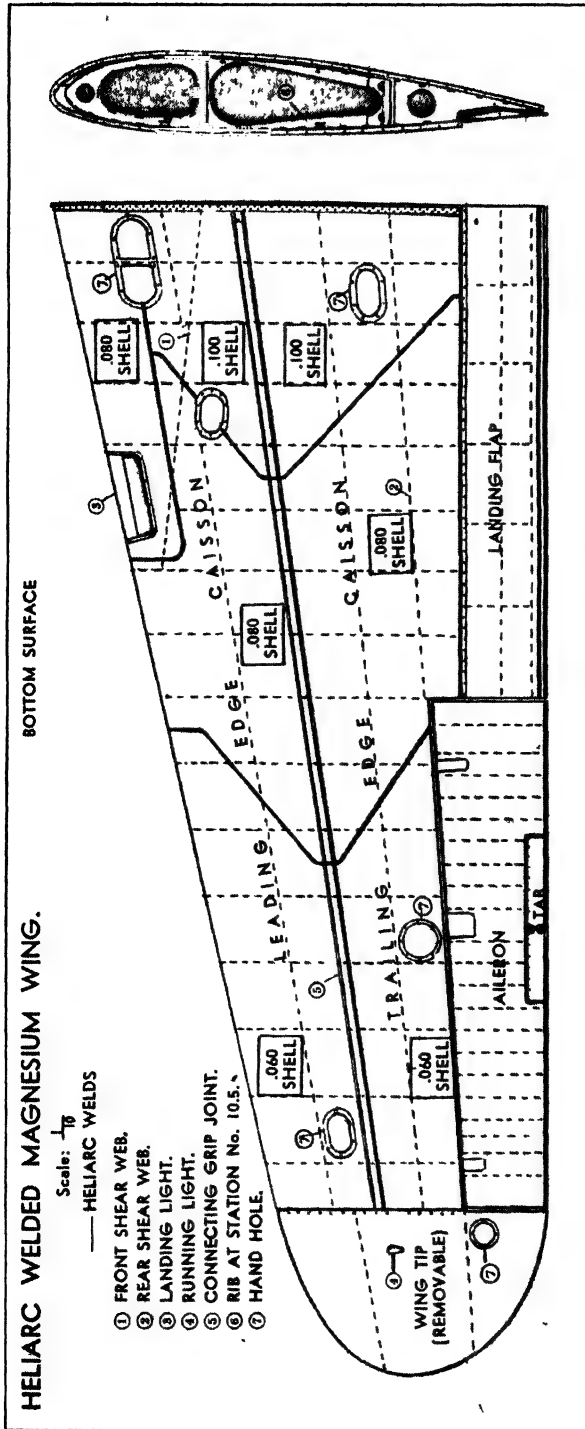
Fig. 4. Welded magnesium wing (bottom surface).

airplane. Fig. 5 shows the completed trailing edge portion of the wing. This caisson can be assembled in a few minutes with a similar leading edge portion into an integral load-carrying structure. On this structure there is fastened a "Heliarc" welded wing tip, Fig. 6, a welded landing flap, Fig. 7, and a welded aileron, Fig. 8.

The internal structures of the nose and tail wing caissons are shown in Fig. 9 and Fig. 10, respectively. These parts are built up of "tee" extrusions and sheet, welded into simple rib arch shapes having approximately the wing airfoil contour. This work is done on the bench in simple, adjustable jigs. The finished ribs are then welded onto the main shear webs and to the connector grip joints. This work is done in rotatable jigs, Fig. 11, and is easily accessible at all places where welding is required.

While the internal structure is being assembled, the monocoque shell panels are being prepared on a steel top bench. The wing root material thickness of the monocoque shell is .150 inch on the top and .100 inch on the bottom. These thicknesses diminish in steps toward the wing tip, where the wing shell is .060 inch thick on both top and bottom, as shown in Fig. 3 and Fig. 4. The butt seams between the sheets of the monocoque shell are scarfed and "Heliarc" welded at an angle of approximately 45° with respect to the principal stresses, so that the welds are subject mainly to shear stresses.
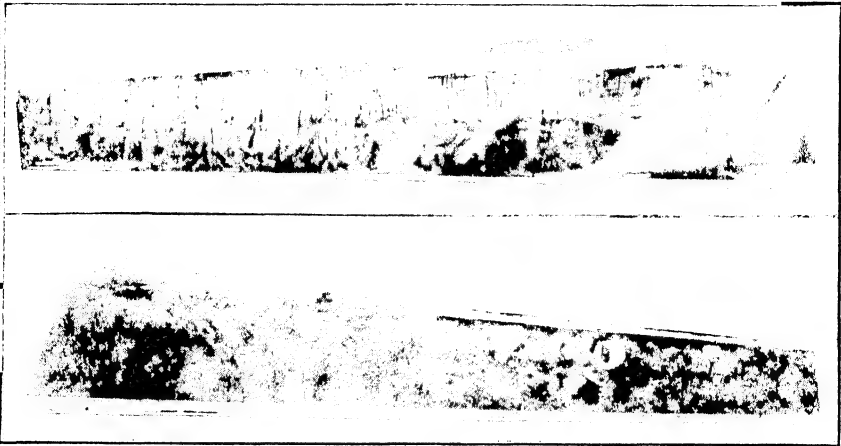
Fig. 5. (Top) Highly polished surface ready for chemical treatment and (bottom) trailing edge caisson.

The rib arches are designed with vertical stanchions at the connector grip joint, alternatively located on the nose and trailing edge caissons, Fig. 9 and Fig. 10. When dismantled, the wing caissons are held in shape by these vertical rib members while, when the wing is assembled, they act as spandrel columns which carry the crushing loads induced by the bending deflection of the wings.

The wing caissons are also equipped with supports and fittings for the controls of the ailerons and flaps, fittings for supporting the whole airplane on the ground from a jacking fixture, landing lights, electrical conduits, etc. All of these accessories are directly welded into the wing structure. External welds are smoothed over to the outer contour surface of the wing. All internal welds are left untouched except for brushing off the powder sediment after welding.

The inner structure, when complete and after inspection, is welded to the

outer monocoque shell in jigs, Fig. 12. These jigs, as first designed, were rather heavy and complicated. Experience has shown that simpler and much lighter jigs would have been just as satisfactory and certainly cheaper and more convenient.

The wing structure also could have been designed on the "spanwise principle", that is by introducing spanwise stringers against the sheet and supporting them from a reduced number of ribs. The authors preferred the "chordwise" system here illustrated, as being structurally sounder and particularly because of its attractive characteristic of greater chordwise rigidity to resist compressibility loads that occur on modern wings of fast airplanes.

Fig. 6. Welded wing tip assembly.

Manufacturing Problems—In almost all welding, a certain amount of shrinkage distortion must be allowed for. Magnesium is no exception to this rule, and this phenomenon was the cause of some of the most persistent and annoying difficulties in the early stages of this development. A considerable number of tests led to making proper allowances in lengths for shrinkage and this difficulty was solved satisfactorily, as far as the dimensional control was concerned, at an early stage of the development. Sharp distortion due to shrinkage proved much more difficult to control. In structures of this nature, distortion manifests itself principally as buckling of the monocoque shell, particularly at those places where the curvature is not pronounced. However, there was developed a simple and satisfactory method of dealing with the buckling distortion, which does not harm the metal either internally or externally. This method has been used on the shell surfaces of the wings described in this paper, and by its use it is possible to obtain smooth, non-buckled surfaces after welding. By this method, heat and pressure are applied to the buckled structure through the use of ironing pads which relieve the internal strain in the sheet.

To make certain that no excessive locked-in strains are set up in "Heliarc" welded structures, experiments were carried out to obtain the absolute value of internal strains in magnesium alloys induced by welding. At the worst, these stresses were found to be of the order of 1000 pounds per square inch maximum, and are, therefore, of little consequence as far as the impairment of the integrity of "Heliarc" welded magnesium alloy structures is concerned. This is probably due to the relatively low modulus of elasticity and low yield strength of these alloys. Both of these physical properties tend to adjust the metal structure readily to any internally imposed strains from welding.

The amount of welding is not indiscriminate. Proportioning of the welded seams to the loads carried through them and selecting the type of weld to best fit the conditions of elastic flexure of the structure should be two recognized principles of electric arc welding application. It has been noticed that on a number of electric arc welded steel structures these principles have not always
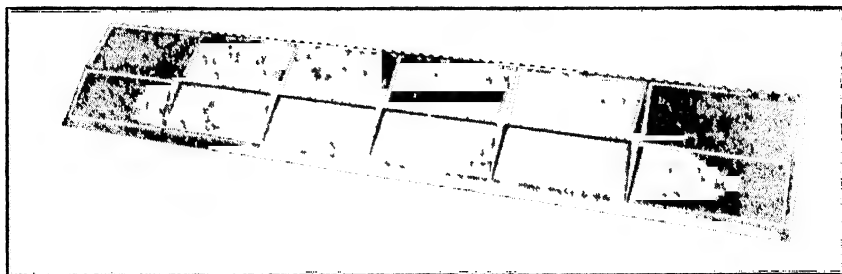
Fig. 7. Landing flap assembly.

been observed. The magnesium alloy "Heliarc" welded wings have been designed with great care in this respect. Full length seams are used only where necessary. Otherwise, the seams are of the interrupted type, either on one side, or of staggered interrupted type on both sides of the edge of a plate or of an extrusion attaching joint. These practices were made possible by the high metallurgical quality of the seams, their uniformly and relatively high strength. For design purposes, the Army Air Force allowed 75.9 per cent of the ultimate tensile strength of the metal to be used as the strength of the welded seams in tension. This figure is based on tests of seams made in the early stages of this development, and much higher uniform values are now being attained consistently as previously noted.

The wing tip and the aileron, (Figs. 6 and 8), were made of .050 inch thick Dowmetal J-1 annealed alloy. The reason that annealed metal was used for these two structures lies in the fact that loads on them are relatively low. Since .050 inch was self-imposed by the authors as the minimum practical sheet thickness of J-1 alloy for this design, it appeared that annealed metal could be used with safety and with the advantage that such material is delivered flatter than the equivalent gauge of the cold-rolled, strain-hardened J1-H sheet. Furthermore, the wing tips were formed to shape by drop hammering heated sheet (approximately 600°F.), which would have obliterated most of the cold-rolled strength of the J1-H alloy.

In point of accomplishment, the wing tips and the ailerons are even more noteworthy than the wings themselves. Both have already been tested for strength and found to be stronger than necessary and also more rigid than expected from past experience with comparable aluminum alloy riveted structures.

The utmost structural simplicity and the small amount of arc welding required to assemble the ailerons and the wing tips distinguishes these units as first class production articles.

The landing flap, Fig. 7, is an open structure, simple and easily accessible for welding. The same few structural elements are used in its assembly as on the wings.

The wings are attached to the airplane center section by riveted aluminum alloy flanges. This joint necessarily was copied from the aluminum alloy wings, because the arc welded wings have to fit, by exchange, a conventional riveted aluminum alloy airplane.

Serviceability of Magnesium—In the past, magnesium alloys have suffered from two generally known and popularly misunderstood faults. One is the general fear of their inflammability and the other is a deep-rooted and, by past performance, somewhat justified, conviction that these alloys corrode rapidly.

As to the first, the experience of the authors is that the fire hazard has

been greatly exaggerated. In spite of the intensive welding development of these alloys in the shops during the last two years, the only fires involving magnesium were those started deliberately for test purposes, or in experiments before helium was used. It was discovered that the zinc chromate primer, generally used by the aircraft industry, acts as a potent fire inhibitor on magnesium, and that it is in fact impossible to ignite these alloys, even artificially, if they are protected by it. Magnesium retains its elastic modulus to much higher temperature than is the case with aluminum alloys. This is an extremely desirable property and in practice it means that a zinc-chromate-protected magnesium alloy structure will not collapse as readily as an aluminum alloy structure might do if exposed to fire.

The weather durability of magnesium aircraft structures in service is still undetermined. However, a wealth of artificial corrosion testing, and also gratifying results of the use of magnesium alloys on several truck bodies through a number of years, furnish convincing proof that corrosion is not as dangerous as is generally believed, provided proper surface protection is given. This protection consists of treating the finished, welded and cleaned structures with sodium dichromate and painting them with standard zinc chromate primer and two coats of finishing lacquer. This protection has been found to be sufficiently elastic under load, as well as abrasion resistant.

One of the least desirable physical characteristics of the magnesium alloys is their inclination to strain corrosion. The elasticity of the surface finish helps here a great deal but, in addition, the authors deliberately avoided stress concentrations in their design and saw to it that the maximum principal stresses anywhere in the wing remain low, viz. 12,600 pounds per square inch maximum in compression and 19,170 pounds per square inch maximum in tension.

Compared to the maximum allowable yield point in tension of 33,000 pounds per square inch for J1-H alloy, this utilization of the material seems wasteful. However, it was done deliberately in order to favor the rigidity of the outer wing shell, and also to diminish tendencies to strain corrosion. It is apparent, however, that as service experience is acquired it may be possible to design these structures for less weight than the equivalent weight of aluminum alloy riveted structures, without abandoning the non-buckling principle.

Static tests of magnesium wings have demonstrated that these wings are
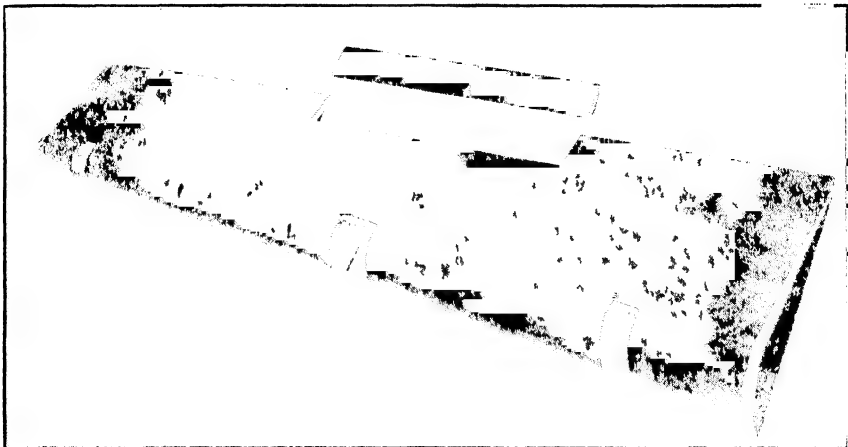
Fig. 8. Aileron and tab assembly.

elastically more flexible in bending than aluminum alloy wings. This is a desirable feature, as it tends to reduce excessive loads in gusty air, particularly when it is realized that the internal damping of magnesium alloys is several times greater than of aluminum alloys. On the other hand, the magnesium wings are more rigid in torsion than corresponding aluminum alloy riveted wings. This is also a very desirable property to eliminate danger from flutter, and can be traced to greater thickness, and to the absence of slippage in welded seams.

Detailed Cost Comparison—Dollar evaluation of the economic advantages of electric arc welding as applied to magnesium aircraft structures is a difficult task because of the many variables and intangibles involved. Direct comparison of the cost of a "Heliarc" welded seam and a riveted seam in the same materials is given hereunder:

Table I—Comparison of Joint Cost Per Foot In .10 Sheet—Approximate Equal Strength

Item	Time	Rate	Cost
"Heliarc" Welded			
Surface preparation	.250 hrs. at	$0.97 per hr.	$0.24
Setup	.083 hrs. at	.97 per hr.	.08
Weld time	.100 hrs. at	1.40 per hr.	.14
Cleanup	.083 hrs. at	.97 per hr.	.08
Helium 1 cu. ft.			.02
Magnesium filler rod & tungsten electrode			.01
Electric current			.01
Total direct cost			$0.58
Overhead on labor at 100%			.56
Total cost per foot			$1.14
Riveted			
Layout and drill 24 holes	.166 hrs. at	$0.97 per hr.	$0.16
Countersink 24 holes	.10 hrs. at	.97 per hr.	.10
Drive 24 rivets	.40 hrs. at	.97 per hr.	.39
24 rivets			.04
Total direct cost			$0.69
Overhead on labor at 100%			.65
Total cost per foot			$1.34

It will be noted that in the comparison of Table I the weld is somewhat less expensive than the equivalent riveted joint. Such a comparison, however, is unduly conservative in that the cost of joining the parts is only a minor element in the overall economic gain to be made.

If the authors' philosophy is followed, namely, that welded magnesium structural design should be directed primarily to simplicity and aerodynamic excellence, it will be found that weights generally equivalent to those of contemporary structures of riveted aluminum alloy will be obtained. There is, therefore, little or no advantage from the standpoint of weight saving. On the
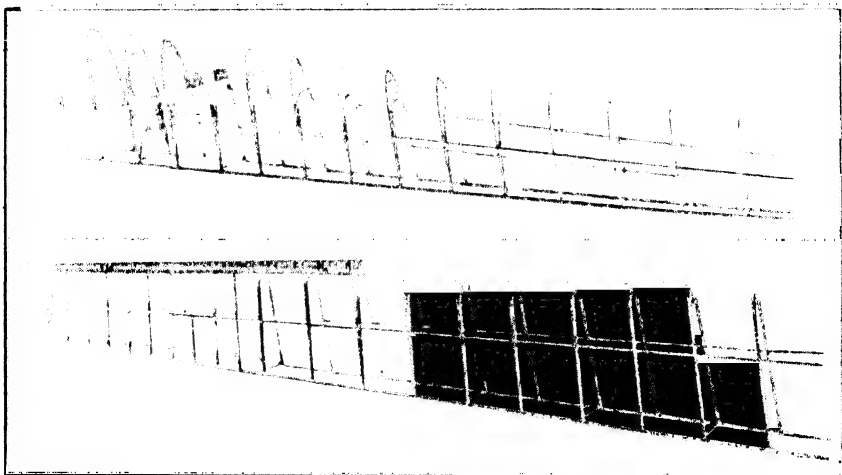
Fig. 9, (above). Leading edge wing frame and Fig. 10, (below). Trailing edge wing frame.

other hand, the reduction in number of parts for a given structure, and the possible reduction of drag of the finished airplane are factors of great importance.

The former advantage may be visualized to a limited extent by reference to Fig. 9. This photograph shows the complete internal structure assembly of the nose portion of the wing. All that remains to accomplish is the attachment by welding of the relatively thick cover sheet to the rib structure. A comparative check with a similar conventional structure indicates that the welded design has slightly more than one-half the number of feet of basic attachment of parts to each other employed in cases where riveted aluminum construction was used. In addition to this fact, the actual number of pieces required in the design is in the order of one-half the number required in the comparable aluminum alloy structure, so that the cost of fabrication may be expected to be reduced in similar measure. Unfortunately, at this writing the welded wings are only being produced in experimental quantities and no cost data on conventional wing structures in comparable quantities are available to the authors.

General Economic Evaluation—The actual structural cost, in itself, is still of minor importance in the overall economic advantage to be gained, however, because the most valuable contribution of this program lies in the possible reduction in drag of the finished airplane. Within the past few years a whole new family of high performance airfoils has been developed in which profile drag reductions of from 30 to 50 per cent have been obtained. These airfoils must be constructed with a degree of accuracy that is virtually impossible to obtain in conventional riveted structures which develop surface waves within the flight range. Monocoque welded magnesium structures, however, are readily adaptable to these requirements. They are designed with comparatively thick skins which do not buckle locally within the normal range of flight loads. Their surface finish can be as smooth as that of a fine automobile, and held within accurate limits. The outer surface of all welded joints may be ground flush with the face of the surrounding sheet so that no measurable inequality occurs at seams or joints. Butt joints and seams in the surface covering are a normal design procedure, so that laps as well as rivet irregularities and local buckling may be completely eliminated. Depending somewhat on cover thick-

ness and internal structure, some slight surface irregularities may exist, but these, at the worst, can be limited to long waves of very low magnitude which do not adversely affect the drag of the structure. In summarizing this point, it may be said that a parasite drag reduction of at least 30 per cent may be obtained through the use of the new low-drag airfoils which, to the best of the authors' knowledge, can only be built to proper accuracy and finish in "Heliarc" welded magnesium, if metal is to be used.

Several extensive studies directed to the dollar value of aerodynamic improvement have been published in the past. One of these * has been selected as representative because it is written by competent personnel experienced in air transport operations and shows careful study of all operative factors in its preparation. To evaluate the direct effect of the possible saving in parasite drag under all conditions of speed, trip length, airplane size, first cost, etc., would require an additional paper longer than this one. However, a near approximation may be made for reasonably assumed conditions. The article referred to uses a modern four-motored transport having a parasite drag
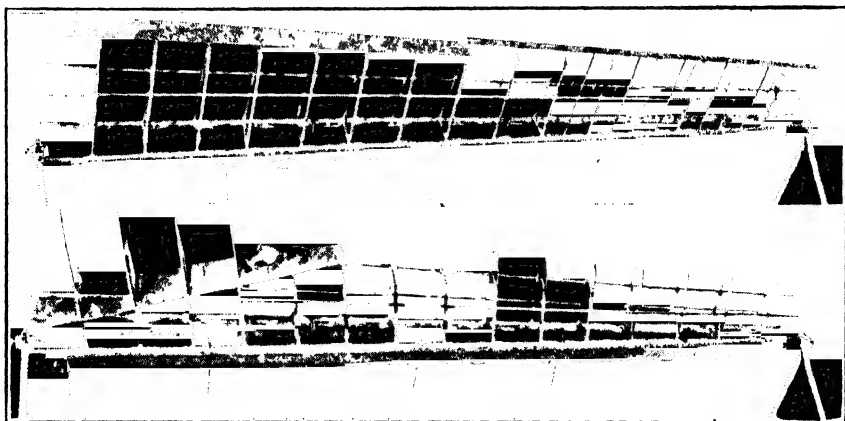
Fig. 11. Trailing edge frame (above) and leading edge frame (below).

coefficient of .024 as an example. For a trip-length of 900 miles, (corresponding to a two-stop transcontinental flight), and an operating speed (block-to-block or station-to-station) of 250 miles per hour, the cost of transporting one ton of payload per mile is estimated as 30 cents. If the parasite drag is reduced 30 per cent to .0168, the cost per ton mile is reduced to 17.5 cents, evidencing a net saving of 12.5 cents. The payload for such a trip in the example airplane may be conservatively assumed to be 2½ tons, so that our gain in operating cost per mile of flight is 31.25 cents. We now multiply the saving per mile by the speed in miles per hour (250) and the reasonable life expectancy of the airplane of at least 15,000 hours, (many modern transports are charged off over a six-year period, which corresponds to nearly 20,000 hours), and we arrive at the rather staggering total of $1,172,000 per airplane. In the light of such figures, it may be seen that from a broad viewpoint it isn't particularly important whether the "Heliarc" weld costs more or less than the riveted joint, as the saving is about five times the total original cost of the airplane. The variation in cost between welding and riveting could be several hundred percent

*"Some Economic Aspects of Transport Airplane Performance" by W. C. Mentzer and Hal E. Nourse. Jour. Aero. Sci., Vol. 7, pp. 227-234, 302-308 (1940)
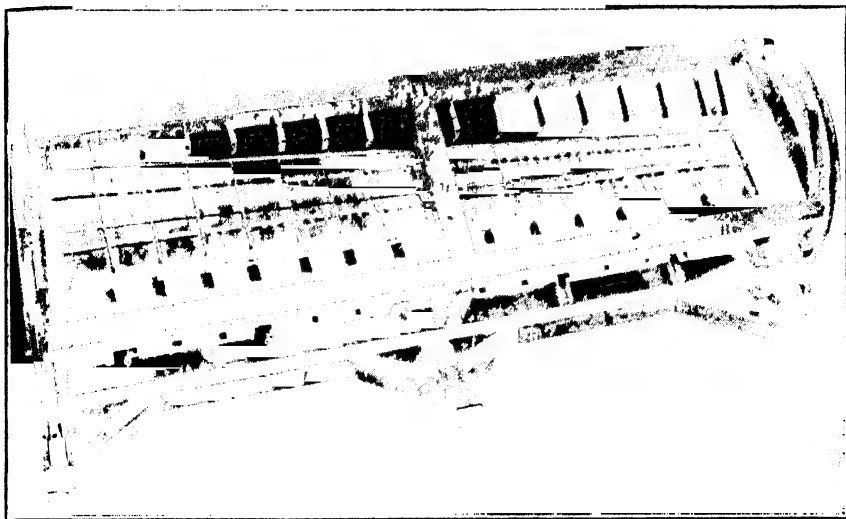
Fig. 12. Main wing jig trailing edge portion.

either way without greatly affecting the ultimate economic value of the aerodynamic gain involved. If we care to make one more step, and multiply the saving per airplane over its life by the approximate number of transports in operation in the United States prior to Pearl Harbor (say 400), the saving over the life of these ships is $468,800,000.

The above figures are conservatively based on modern four-motored transports of a type in use on American airlines in 1941. Recent airplane developments presage the day when aerodynamic refinements may greatly reduce the use of items contributing to the parasite drag, such as fuselage, tails, and engine nacelles. On the all-wing airplane of the future, the difference in drag between a conventional riveted aluminum airfoil and the low-drag wing made possible through magnesium "Heliarc" welded may be as much as 50 per cent. Leaving all other assumptions as they were, and for the same size airplane the saving per ton-mile becomes approximately 20 cents, the saving over the life of the airplane $1,875,000, and over the life of the 400-ship fleet, $750,000,000.

These figures are all based on a 900-mile trip. After the war is over, transports flying across the nation in eight to ten hours, and with only one stop, will soon go into service. On such longer hauls, the figures become even more impressive because the longer trips require a higher percentage of useful load to be devoted to fuel, and this increases the percentage of saving per ton-mile through reduction in drag, out of all proportion to the increase in trip length.

Truly, the United States, with an unlimited supply of sea water, and the only known large reserves of helium gas, is in an enviable position. Perhaps the green glow of the "Heliarc" is tinged with gold—or something even better—the power to serve mankind through an ever-increasing abundance of the things that make life worthwhile.

Chapter V—Arc Welding Airplane Boilers

By H. A. Lebert and S. B. Willoughby,
Inspector and Arc Welder, respectively,
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S. B. Willoughby

Subject Matter: Arc welding has made possible a new type of boiler of light weight, low cost, and long service life. Arc welded seams withstand the corrugating process used in forming the core and shell of the boiler, whereas other types of welded seams do not.

H. A. Lebert

United Airlines, as one of the leading users of DC-3 Douglas air transports, has long been aware of what might be called a "weak link" in this airplane's makeup, namely: the heating system and, more specifically, the boiler unit of that heating system.

The DC-3 has always used the "steam" system wherein water is converted into steam by contact with metal which has been heated by the engine exhaust gases. The steam is conducted to a tubular radiator inside the airplane and gives up its heat to a stream of air brought in through a "nose door" located in the nose of the plane's fuselage and carried through the radiator by means of ducts to the various parts of the plane's interior. The steam condensate is returned to the boiler and again converted into steam.

Suitable valves and regulators are used to maintain about 15 pounds steam pressure throughout the system. A surge tank serves as a reservoir to compensate for varying demands on the system.

.The radiators give practically no trouble in service; the valves and piping give average or expected service while the boilers, as mentioned before, are the "weak link" in the heating system.

The original Douglas factory boiler was of tubular construction using some 18 tubes of varying length by ½-inch diameter and made of stainless steel. These tubes were welded to suitable headers and located in the path of the exhaust gases from the engine. Water was fed into the lower header or sump and converted into steam as it contacted the exhaust-heated tubes. The steam thus formed was conducted to the radiator where it gave up its heat to the incoming fresh air for the cabin. The resulting condensate was returned to the boiler to be used again.

This type boiler, which we shall refer to as the tubular type boiler, has been used with success by some airlines notably American Airlines Inc. In fact this type boiler was so improved by the use of arc welding that two members of American Airlines personnel won well deserved awards from the James F. Lincoln Arc Welding Foundation in the Foundation's 1937-38 program.

In view of such improvement the question might well be asked: "Why a different type of boiler?" The answer lies in the fact that while all Douglas DC-3 airplanes are like so many peas in a pod in many respects, there is, however, one important difference between the DC-3 equipment as used by the various leading airlines. That difference is the make and type of engine used.

To clarify: American Airlines uses the Wright, single-row, 9-cylinder, air-cooled engine whereas United Airlines, in contrast, uses the Pratt and Whitney twin-row, 14-cylinder, air-cooled engine. Since both these engines give off plenty of hot exhaust gases for boiler heating, the question is fair: "What difference does it make which engine is used?" The answer is vibration.

Fig. 1. Forming the stainless steel after it is cut to proper size.

The periods of vibration encountered with the use of the twin-row, 14-cylinder engine, while smoother to the passengers nevertheless are anything but friendly to the stainless steel tubes in the tubular-type boiler. The welds did not fail under vibration but the tubes did. Seams would open in the bends of the tubes with clock-like regularity after about 100 hours' service.

Thus, it can be seen that the answer to one airline engineer's prayers is not necessarily the answer to some other airline's problem.

In order to combat this "demon" vibration, one of the writers, H. A. Lebert, early in 1938 designed what is known as the United Airlines "corrugated boiler" This design did not permit vibration of any of its parts yet provided flexibility to compensate for wide extremes of temperature with attendant expansion and contraction. The first units were made in a drop hammer as stampings, that is, sheets of stainless steel were formed into half-

tubes, placed between male and female dies and the corrugations stamped one at a time. Then the two half-tubes were trimmed to match and gas welded on each side to form a continuous corrugated tube. This tube formed the core of the boiler. Two similar stampings, but with shallower corrugations, were then stamped, fitted and welded on the outside of this core to form the boiler shell or jacket. The hot exhaust gases from the engine came in contact with the core, thus heating and converting into steam the water which was introduced between the core and the jacket. The finished boiler looked very much like the boiler shown in the accompanying photographs. It was a success in combating vibration and gave at least twice the service life previously obtained from the tubular type boiler.

The Douglas factory had repeatedly reduced the price on its tubular type boiler until it stabilized at $150. United Airlines could make the stamped, gas welded, corrugated boiler for an average price of $60 per unit. This price would vary slightly on different lots of manufacture depending on whether a standard grade of 18-8 stainless steel or the more expensive Inconel was used.

We should like to point out that all price figures used are United's cost in time and material plus 100 per cent for overhead.

It might also be well to mention at this point that United Airlines has never patented this corrugated type boiler but has made its design available to the industry. For a time, United supplied such airlines as Northwest, Pennsylvania-Central, Pan-American and K.L.M. (Holland) with corrugated boilers of United's manufacture. Many of these companies now make their own boilers patterned on United's design. A few units are still sold by United but United's prime interest is the supplying of the needs of its own fleet.

As mentioned above, the stamped, gas welded, corrugated boilers cost approximately $60 to manufacture. This $60 represented $15 for labor and $15 for material or $30 per boiler, plus 100 per cent overhead.

No one could or did object to a boiler cost of $60 compared with a factory price of $150, especially when the corrugated boiler gave a service time of 250 hours as compared with 100 hours for the tubular-type boiler. Since the tubular-type represented an investment of $150, it was felt that repair should be made at the time of 100-hour failure. Such repair was usually made with the result that an additional 25 to 75 hours service was

Fig. 2. Welding core blanks in fixture.

obtained. However, it must be remembered that this "first failure" is important as it may result in a "cold trip" with resultant passenger discomfort, delay, etc. These are intangible costs but of great importance in the successful operation of any airline.

With its greatly reduced first cost the corrugated boiler could be junked at the time of its first failure (250 hours) on a "dollars and cents" basis if desired and thus not run the risk of an early second failure after repair as happened with the repaired tubular-type boilers.

The stamped, gas welded, corrugated boiler was, in brief, a decided improvement in cost and service over the tubular-type boiler for use on twin-row engined DC-3 airplanes. However, the writers were not satisfied. The two welds on either side of the core represented a lot of welding that was not easy to get at. The two stamped halves of the core had to be trimmed to fit—a waste of material and time. The service time ceiling, we felt, could be raised.

This thought kept recurring: why not roll a sheet of stainless into the correct size tube and then roll the corrugations into this tube?

Always the same speculative answer: "Can't be done! Even if the stainless steel would take such a beating the weld never would!"

And the critics were right insofar as a gas welded seam was concerned. But they failed to take into account an arc welded seam!

So it was that early in 1940 we started on the process that has evolved into the present sequence as shown in the photographs with this paper. Through the use of arc welding, we have reduced the manufacture of corrugated boilers to its simplest form. The least expensive type of 18-8 stainless steel was found to last almost as long as the more expensive types. Labor operations have been reduced to a minimum.
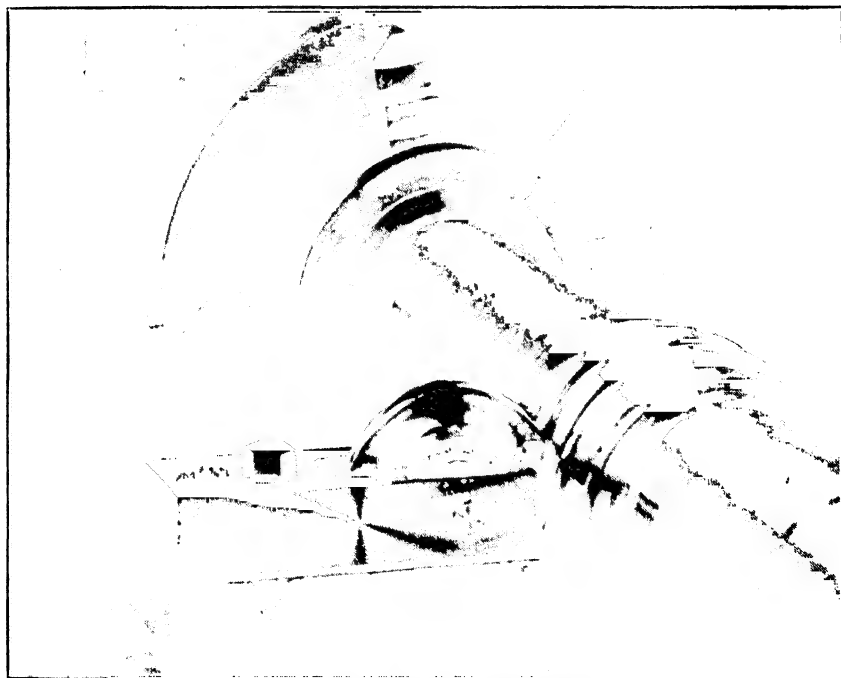
Fig. 3. Lathe used in corrugation.
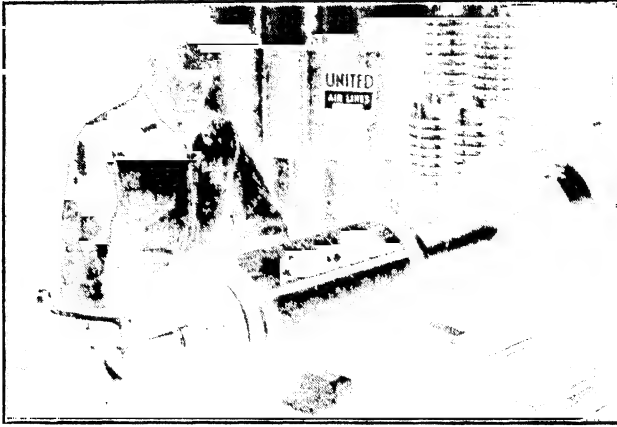
Fig. 4. Set-up for turning concentric grooves.

To break down a typical lot of boilers, let us look at Shop Work Order No. 9797 for the manufacture of 80 corrugated boilers. This specific work order when completed had a total labor charge of $472 35 covering 531¾ man hours. The total material charge was $624.94 giving a total of $1097.29 for 80 boilers or a unit cost in time and material of $13 72, ($27 44 each with 100 per cent overhead). These 80 boilers gave an average service life of 400 hours. In view of the extreme low first cost it is apparent that a boiler can be discarded upon its first failure. There is no high first cost to dictate repairs and questionable second-hand life.

It will, thus, be seen that boiler life had been stepped up some 4 times

Fig. 5. Grooves formed in welded seam.

(100 hours to 400 hours) while cost had been stepped down from $150 to $27.44 ($13.72 plus 100 per cent for overhead). Or to compare with the former stamped and gas welded corrugated boiler, we have a reduction in cost from $60 to $27.44 a saving of $32.56 or 54 plus per cent. The total fleet savings on 40 DC-3 airplanes over a year's time would approximate the saving per unit multiplied by 400 (10 boilers per plane per year) or $13,024.

The yearly savings over the factory supplied boiler at $150 would be much higher: $150 less $27.44 times 400 or $49,024 and that would be on the assumption the factory or tubular boilers lasted as long as the corrugated boilers. Actually the tubular type has but one half to one fourth the life of the corrugated boiler when used in conjunction with twin-row engines.
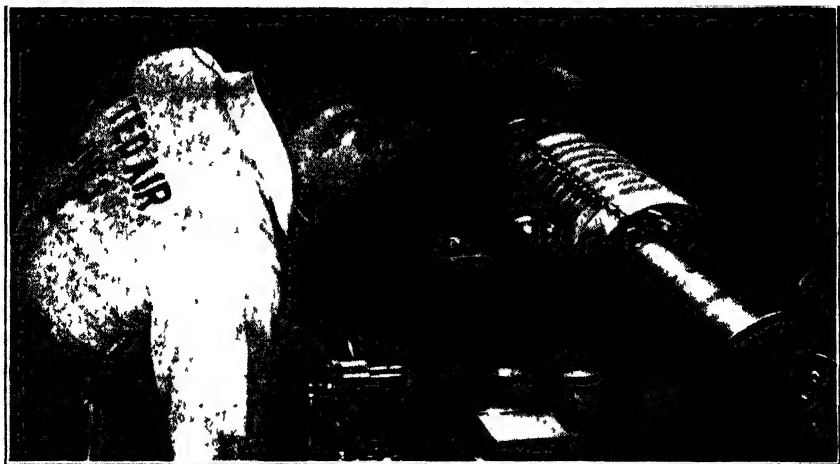
Fig. 8. Another view of the corrugating operation.

It would not be fair to compute savings to the entire industry since the tubular boiler has proved its merit on single-row engines such as used by American Airlines. However, to the credit of the corrugated boiler it can be said that over 2000 units have been manufactured by United Airlines alone. Of these, at least 1000 have been of arc welded and rolled construction. They are in service in the far corners of the earth having been sold to such far-flung lines as Pan-American and K.L.M. of Holland. In addition, our design has been adopted by Northwest Airlines and Pennsylvania-Central for their own manufacture since United has made the corrugated design available to the industry at no cost. So we can safely say the arc welded rolled corrugated boiler has been a decided step forward in the never-ending search for the ultimate in airline passenger comfort, and at a cost never before reached.

If such a picture seems fantastic, let us turn to the photographs showing the steps in the boiler's manufacture. If the old saying, "It's the simple things that have the greater merit" ever held, it holds for this boiler construction made possible by arc welding.

Photograph, Fig. 1 shows the first forming of the .050 inch thick stainless steel after being cut into the proper size. Core blanks are here being rolled into tube form. Each blank in the flat is 18-inches by $28\frac{13}{32}$-inches so that when a standard factory stock sheet (36-inches by 120-inches) is
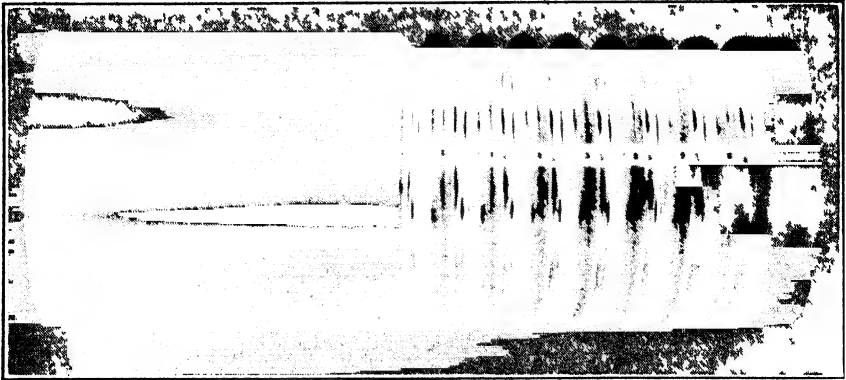
Fig. 7. A finished core with welded shell blank ready for slipping into position.

cut down the center we avoid waste material as the trim is used to make the upper and lower sump blanks (6-inches by 12-inches) The outer shell for the boiler is likewise formed into a tube before it is welded The shell blank is $11\frac{1}{8}$-inches by $29\frac{7}{32}$-inches The attachment lugs and the steam outlet neck use up the narrow trim strips so none of the metal is wasted

After the core blanks have been rolled into tube or pipe sections they are clamped into the welding fixture shown in Fig 2

The supporting pipe shown in Fig 2 has a copper backing plate to back up the weld and to dissipate excess heat Two heavy spaced bars provide a clamp for holding the core in position The core is first tack welded in about a dozen places and then a continuous weld is made as shown The electrode used gives good penetration and forms a ductile weld—the heart of this method of boiler fabrication After the flux and some of the surplus weld have been removed we are ready for the machine shown in Fig 3

The machine in Fig 3 is a standard lathe holding a large steel shaft on which has been turned several concentric grooves The ball-bearing-sup

Fig. 8, (left). Rolling the corrugations into the shell. Fig. 9, (right). Drop hammer operation for forming the boiler sumps.

ported roll shown mounted on the carriage is shaped to mesh with the roll grooves on the shaft. Metal clearance for the boiler material is allowed between the two rolls. All the roll surfaces are hardened and polished to stand up under the action of rolling the stainless steel as well as the abrasive action of any stray particles of flux remaining.

The setup shown has rolled over a thousand boilers with practically no maintenance cost.
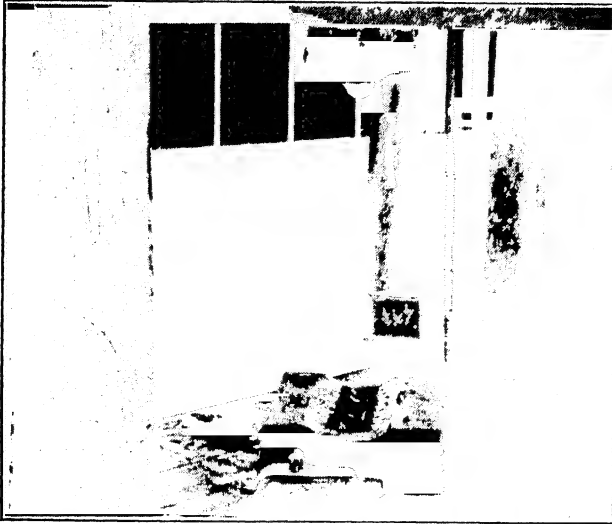
Fig. 10. Stainless steel blank changed into sump after one blow.

Fig. 4 shows a boiler core blank in position on the roll and ready for having the first corrugation formed. End plates held in position on the roll proper by set screws, accurately locate the position of the first corrugation. These end plates also serve to keep the first corrugation at true right angles with the core. The first corrugation is important as it forms or provides the "lead" or master guide on which all the other corrugations are patterned.

A light coat of oil is put on the inside of the core blank before it is placed on the roll. No lubrication is used on the outside.

After the first corrugation has been formed, the end plates are removed since each corrugation now being rolled is guided and spaced by the last preceding corrugation riding on the outer groove of the main roll.

In Fig. 5 can be seen the terrific punishment the arc welded seam is subjected to. The ability of the arc weld to withstand this roll-forming action is what makes this inexpensive, efficient method of boiler fabrication possible. Flame or gas welded core blanks crack and tear under this rolling action.

Since the rolling operation is the "heart" of this method of boiler fabrication we have added extra view of the operation in Fig. 6.

The standard depth of the corrugation is ½-inch. The operator secures this depth by reading the indicator on the feed screw. In addition, he uses a depth gauge as occasionally some lots of sheet stock are harder than others with a corresponding greater amount of "spring back".

Fig. 7 shows a finished core with a welded shell blank about to be
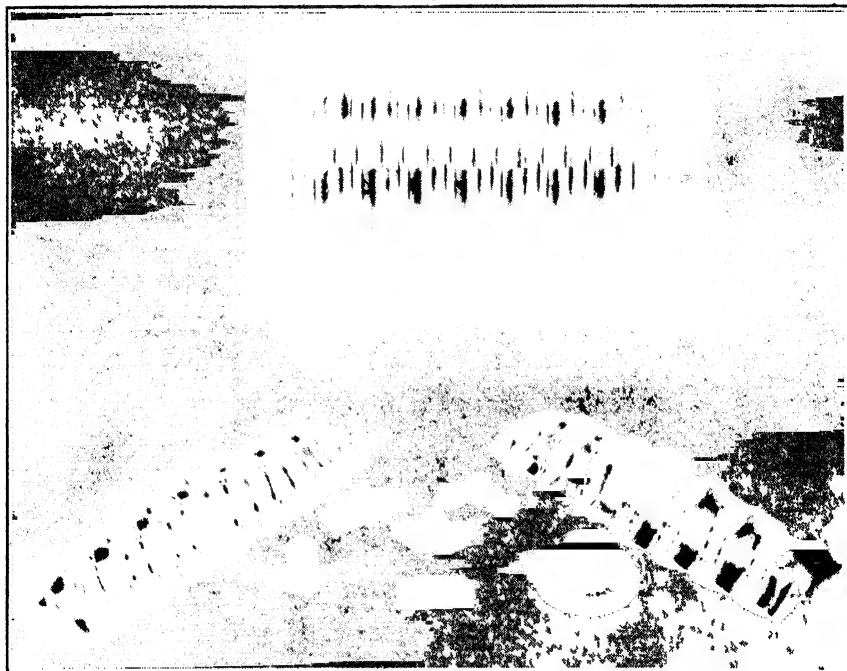
Fig. 11. Component parts of boiler.

Fig. 12. Welding jig used for assembly.

slipped into position over the core. After the shell blank is in position on the core, the shell ends are arc welded to the core and the assembly again placed on the roll as shown in Fig. 8.

In Fig. 8 we have the corrugations being rolled into the shell. The shell and core corrugations have to match as the core is being guided by the inner roll grooves. The shell corrugations are only 5/16-inch deep but the arc welds are subjected to considerable tension since both ends of the shell are welded to the core with the result that the shell is really being stretched into place whereas the core could pull metal from the unrolled end during its forming or "corrugating" process.

Fig. 13. Method of sizing each end of boiler.

Note how the core weld has "left its mark" on the shell surface, thus showing the extreme pressures that weld and metal are subjected to.

Figs. 9 and 10 show the drop hammer operation for forming the boiler sumps. Two zinc dies as shown convert the stainless steel blank (.050 inch thick) into a sump with one blow or impact.

Both upper and lower sumps are the same stamping.

Fig. 10 shows the stainless steel blank changed into a sump after one blow or impact from the upper die.

Fig. 11 shows the component parts of the boiler at this stage of assembly.

The shell has had elongated holes burned through at each corrugation. These elongated holes will permit the steam, which will form between the shell and the core, to escape into the upper or steam sump. An equal number of holes but much smaller in size have been made in the side of the shell directly opposite the steam vents. These smaller holes permit the water to pass from the lower or water sump up into the space between the shell and the core. It will be remembered that the core corrugations are 1/2 inch deep while the shell corrugations are 5/16-inch deep. It is the space thus created that acts as the steam-forming chamber.

Fig. 14, (left). Inspection for leaks. Fig. 15, (right). A finished boiler.

The sump in the lower lefthand corner is the water sump and will have the pipe threaded boss welded into it while the sump in the lower right hand corner will have the steam outlet flange welded into it

The lugs for attaching the boiler to the airplane exhaust pipe are shown in the lower center directly above the boiler's nameplate

The welding jig shown in Fig 12 is used for the assembly of sumps, steam outlet flange, water inlet fitting and attaching lugs in accurate position on the boiler core and shell Such assembly, of course, makes all boilers readily interchangeable on any airplane

So that all boilers will have the proper fit on any airplane exhaust pipe we size each end of the boiler as shown in Fig 13 The upper or front end of the boiler has a plug to size the inside diameter while the lower or rear end of the boiler is sized in a ring

The bar leading down to the steam outlet holds the boiler so that it can be pulled out of the ring The recessed plate on the operator's right is moved to the left until it contacts the boiler shell's corrugations and thus holds the boiler for removal of the plug in the upper or front end

The press used is air operated with the control lever mounted on the right upright

Inspection of the boiler, (See Fig 14), is made after it has been sand-blasted to remove all weld slag The boiler is plugged at the steam outlet connection and connected to an airline at the water inlet fitting Under 110 pounds air pressure the boiler is submerged under water for the detection of any flaws or pin holes If any are found they are welded and the boiler again tested under pressure

In Fig 15, we see the finished boiler ready for stock or installation on an airplane It weighs slightly under 15 pounds as compared to approximately 30 pounds for most tubular-type boilers

The Airlines estimate that every pound of surplus weight which can be removed from their transport planes is worth $20 per year On this basis, we can claim a saving of $300 per plane per year in weight reduction Since our boiler cost (with 100 per cent for overhead) was just under $30 and each plane required 10 boilers per year, we are forced to the paradoxical conclusion that arc welding as exemplified in the rolled, corrugated boiler has given the company good boilers at no cost

Chapter VI—Arc Welding of Airplane Parts

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W. S. Evans

Subject Matter: The general procedure to be followed in determining whether a part should be fabricated by arc welding and the procedure applied to several parts of an airplane. The welding sequence for a landing-gear support assembly is given in detail. A new design for tube attachment replaces the usual "fishmouth".

Arc welding has been for years an established commercial process. Only recently, however, has the aircraft industry availed itself of the numerous advantages offered by this method of assembly. Although its use has been steadily increasing, the full potentialities of its application have not yet been realized. Where arc welding is to be used, the designer must consider the method of fabrication before releasing the drawing for production. It is the purpose of this article to illustrate the method of application of arc welding in aircraft production.

First, it may be well to discuss the general procedure which may be followed in determining whether a part should or should not be fabricated with arc welding. Assembly processes which are in common use are:

- Arc Welding
- Oxy-acetylene Welding
- Silver Brazing
- Copper Brazing
- Resistance Welding
    1. Spot Welding
    2. Flash-butt Welding
    3. Butt Welding (push type)
    4. Seam Welding
- Bolting
- Riveting

Each method is subject to design limitations and the cost of manufacture of the assembly must include the fabrication costs of the component parts as well as actual assembly time. If the cost of producing the detail parts is increased more than the savings resulting from a particular process; the design is not sound—other factors being equal. It is important to weigh the advantages of a process at the time preliminary design is made to avoid later redesign because of certain process limitations.

Frequently, a designing or engineering department or a particular manufacturer inadvertantly becomes accustomed to the use of one or more of these

Fig. 1. Section of engine mount ring assembly showing box-type gusset.

processes and fails to give fair, unprejudiced consideration to the use of the best possible process. A certain amount of this "inertia" was present in the aircraft industry. However, with the advent of "all-out" effort, a great deal of thought has been expended in developing better production methods resulting in greater production at less cost.

If, after all methods of assembly have been investigated, it is decided to use arc welding, the following process development procedure may be used. It is not necessary, in all cases, to use every step that will be mentioned. It is wise, however, to consider the possibilities presented by each step.

Laboratory and Test Procedure—If the design is new or much different from designs in use, it may be necessary to obtain experimental and factual data to back up the choice of process. Metallurgical and structural characteristics of a design detail, such as a joint design, can be established by these tests.

Due to "high strength per unit weight requirement" of many aircraft parts, it is necessary to use alloy steels. The section thickness of alloy steels, as well as mild steel, is a critical design factor. Welding machine and electrode manufacturers generally make available average physical values which can

be used only where a relatively high factor of safety exists or (in the case of certain alloys) where heat treatment after welding is employed. The strength of "As welded" work will vary considerably, depending on the technique used and upon the thickness of stock being welded. These data should be determined in the laboratory and should be available to the design engineer.

With these data, a final design may be developed taking advantage of the following general rules:

1. Proper Joint Selection.

Edge welds should not be used where maximum stress is at root of joint. Butt joints should be preferred to single-lap joints in pure tension. Sufficient scarfing must be available to insure proper penetration. These are only illustrative examples of a subject that is beyond the scope of this paper.

2. Material.

The material best suited to meet all requirements should be selected. Many aircraft designers arbitrarily use chrome-moly alloys, where mild steel would prove most satisfactory.

3. Prefabricated Parts.

Selection of rolled sections, plate, forgings, tubing or machined component parts to meet structural and welding requirements must be made.

4. Forming.

Where inexpensive mechanical forming is involved, parts should be so designed as to use the least amount of welding. For example, in an open-topped box section the assembly could be made of five separate flat pieces, all requiring welding on each edge except the top. This is obviously more expensive than forming the part from one piece by blanking out a cross-shaped section and bending up the sides, welding only the closing edges.

5. Location of Weld.

Use weld metal in the most effective way. A fillet weld in one location may be more effective than the same fillet in a different place.
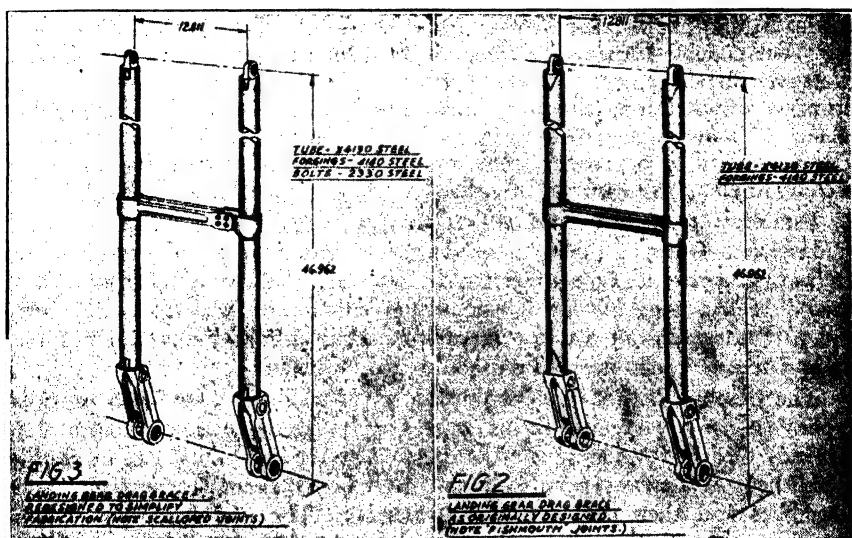
Fig. 2. (right). Landing gear drag brace as originally designed. Fig. 3. (left). Landing gear drag brace redesigned to simplify fabrication.
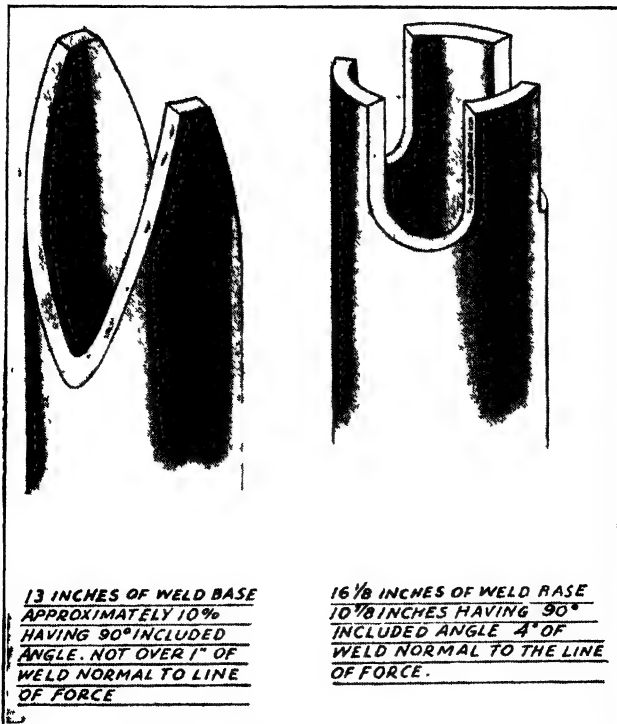
Fig. 4a. (left). Conventional fish mouth design and Fig. 4b, (right). New scalloped design for tubing attachment.

On new designs, or changeovers it is a simple matter, in many cases, to fabricate samples for destructive test in the laboratory. Such samples will bring out possible future shop complications, such as cracking, inaccessibility, excessive shrinkage, etc. In some instances, where fatigue stresses are of primary consideration, laboratory tests on a specific part are imperative, due to lack of knowledge on the fatigue characteristics of arc welded structures. The possibility of deviations from certain questionable design limitations, at present in effect in Government specifications, may thus be determined.

Establishing Shop Procedure—A correct shop welding procedure must be developed to insure quality coupled with minimum cost. Order of assembly, preheating, size and type of electrode, machine settings, number of beads, sizes of welds, joint and metal preparation, subsequent heat treating, if any, and part tolerances all play an important part in this procedure. If possible, jig and fixture recommendations should also be made.

The simplest method is to establish a set of conditions, based on previous experience, and vary one factor at a time until the correct procedure is evolved. Order of assembly is often dictated by the design and can be readily established. Wherever possible it is advisable to assemble parts into sub-assemblies and then into the major assembly. The prefabrication of sub-assemblies permits the use of less skilled labor which is an important item particularly under present conditions. Such a procedure is followed in the assembly of the landing gear support which is discussed later.

Preheating should be avoided if possible because of the increase in assembly cost and the necessity for additional equipment. It is most commonly employed in the welding of closed sections and complicated shapes where stress concentrations in the welds may cause cracking. Structures which may "give" slightly to absorb the welding stresses seldom require preheating.

Size and type of rod is ordinarily determined by past experience or the recommendations of a rod manufacturer supported by laboratory and production tests. The alloy steel used in aircraft, usually requires the use of a coated alloy rod capable of subsequent heat treatment, to approximate results of simultaneous parent metal heat treatment. Size of electrode is determined by the thickness of the parts to be welded and the type of bead. Single-pass beads will require a larger rod size than two-pass beads for the same joint. While a single-pass bead is usually the most economical, it may not be structurally sound due to lack of filler metal and penetration on a particular joint. Metallurgical examination to determine grain size of multiple-bead versus single- or double-pass welding must be considered. Structural and heat treat requirements will dictate the final weld procedure.

The arc characteristics indicate the proper machine setting. A smooth even arc with a minimum of spatter will generally produce the most satisfactory weld. Jigs and fixtures must be designed for accessibility and ease of assembly. Setup time is an important factor in welding costs and appreciable savings will result from good jig design. Frequently, the use of two or more jigs per-
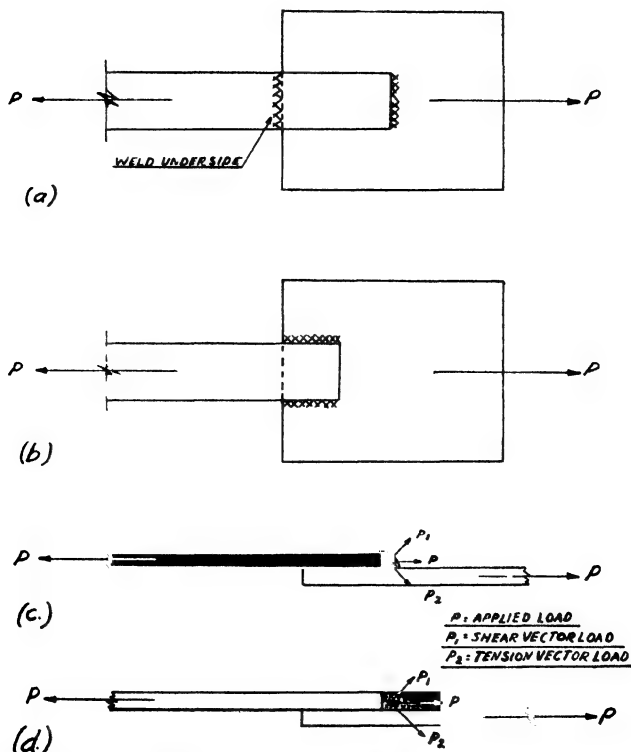
Fig. 5. Effect of location of weld fillet with respect to load.

mitting the use of unskilled labor for loading and unloading will result in remarkable saving.

A certain tolerance should be allowed for the dissolution of welding stresses, thus eliminating possible inherent cracking. It is often practical to design a particular part to permit distortion to take place in a predetermined direction. This will minimize straightening or, if the part is to be machined after welding, the distortion can take place where the machining will eliminate it. Positioning is important in jig design. Horizontal welding is faster and less fatiguing than vertical or overhead and should be used wherever possible.

Part tolerances are set up by the engineering drawing. However, shop practice may necessitate a change to insure sound welds. The combination of a minus tolerance on one part and a plus tolerance on a mating part may lead to difficulties. Too wide a gap is difficult to weld and is not conducive to structurally sound welds. Tightening of tolerances may increase machining costs and this must be balanced against improved weldability.
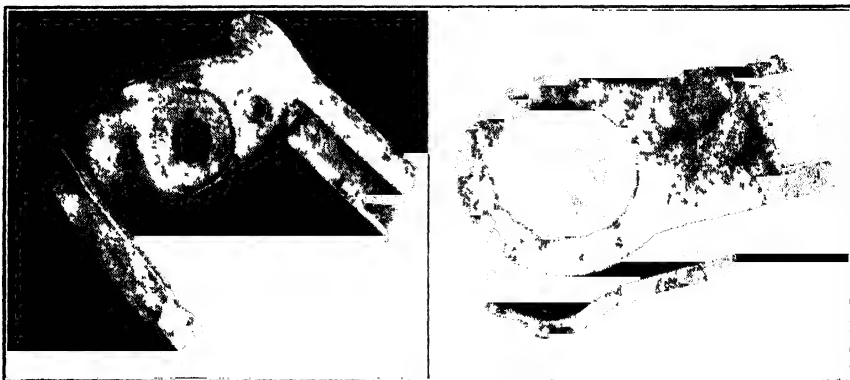
Fig. 6. (left). Unmachined landing gear support assembly. Fig. 7. (right). End view of landing gear support assembly.

Correcting Defects in Established Shop Procedure—Defects in an established shop procedure sometimes occur due to unforeseen complications. A change in the chemical analysis of rod or parent metal may lead to cracking difficulties. Slight variations in parts may change the stress distribution during welding producing excessive distortion or weld cracks. Altering sequence of welding or other procedures may be necessary to minimize these conditions.

Perhaps the most common problem in aircraft welding is cracking. It should be realized that cracks result from welding stress which is greater than the ultimate strength of the material. An excellent example of designs conducive to cracking is the box gusset used on aircraft engine mounts, (See Fig. 1). Here we have a closed section where it is difficult to dissipate the welding stresses. Very elaborate procedures have been developed to overcome this problem. One of the most successful solutions is to lay the bead in such a manner that the weld ends in the center of a straight bead section and not on a curve or angle. Totally or partially welded gusset plates may require slight "dishing" to eliminate tensional draw stresses. Also, high-speed production welding may require preheating.

Jigs or fixtures may be too light, causing difficulty in holding tolerances. If reconstruction of jig is too costly, inexpensive cooling of critical sections through the use of "soldered-on" copper water pipes is, in some instances,

a simple solution. In some cases, regardless of jig construction, a high shop-duty cycle may require water cooling.

The repair of cracked welds is not difficult. It is, however, necessary to grind out all of the crack before laying the repair bead. If any of the crack remains it will cause failure of the new bead. Some care is necessary in determining when the crack is completely removed. A magnetic inspection machine can be effectively used for this determination.

The items just discussed are typical shop complications which must be corrected on the job.

Time Study—After final production procedure is established, a time study is in order, giving definite labor costs and correlating necessary departmental subassembly production with total plant aircraft production. In assembling time data, every effort must be made to obtain facts under actual production conditions. Proper allowance for fatigue and relaxation must be made. A number of time studies should be obtained on, if possible, several workmen in order to obtain a representative cross section of departmental labor costs. In comparing production time on various processes, all factors particular to any one process must be considered. If an arc welded assembly permits broader tolerances than another assembly method resulting in reduced machining time, this factor must be considered as well as the actual process time. Where preparation of component parts is similar as in arc and gas welding, the actual process time will be the determining factor.

Time study data is based on the actual welding time plus an allowance of 25 per cent for tacking, straightening, cleaning, delays and relaxation.

Final Savings—If a part is a "changeover", final savings should be recorded, including time, quality and speed. This is important, as future designs may be developed based on past experience. In this connection it should be noted that arc welding has a number of "hidden" advantages which enable a manufacturer to give his customer "more for less."

This process permits quick change in design, to meet a new requirement,
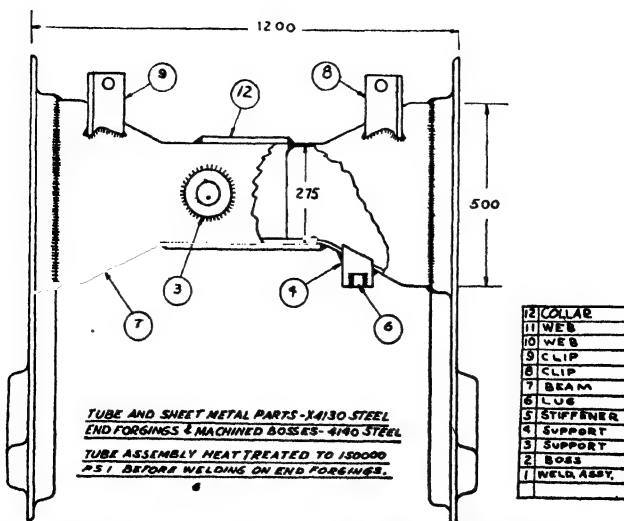
Fig. 8. Side view of landing gear support with cut-away to show interior welding.

or to correct a fault in an existing design. Such changes are impossible to make quickly, at low cost, if a supply of castings or forgings is on hand. If the parts are bolted or riveted together, a change may involve punching-die or drill-jig alterations. Arc welding permits making most changes instantly, and also changing stock parts to latest design.

Comparatively little time-consuming preparation is actually required to go into production on a new part, as no patterns or other preliminary preparation is required. Removal of metal by machining may be held to a minimum, and where rolled sections are used, physical defects such as blow holes, sand inclusions, etc., may be virtually eliminated. Salvaging scrap work is readily performed in most cases.

A final evaluation of costs must include both labor and material. The arbitrary figure of 100 per cent of labor and material used in computing overhead is well below actual overhead costs. However, this figure will serve to give a suitable conservative means of comparison. Pro-rated equipment costs are not included as they are relatively equal for both arc and gas welding and are negligible when compared with other costs.
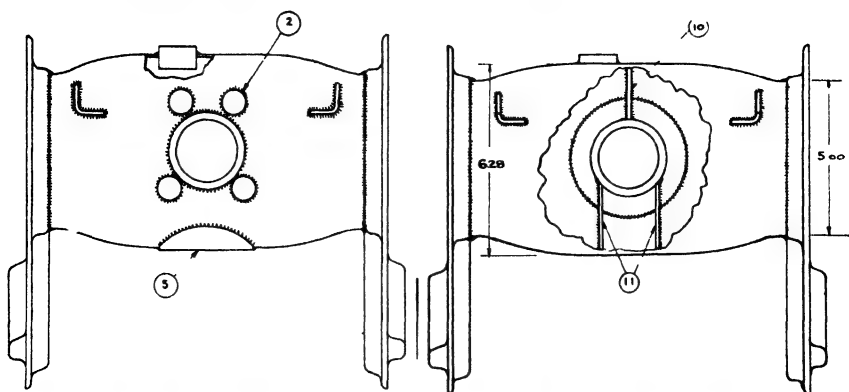
Fig. 9, (left). Top view of landing gear support with cut-away to show welding of a support. Fig. 10, (right). Top view of landing gear support with cut-away showing welding of webs on gussets.

Electrical energy and electrodes are the materials used in arc welding. Power is sold in kilowatt hours. The KWH used by a welding machine depends on the ampere and volt settings and the welding time.

To complete the picture, tooling costs, equipment depreciation, floor space and engineering labor can be included where considered necessary. A comparison of total cost obtained will indicate the savings resulting from a particular choice.

To illustrate the foregoing with actual aircraft parts, a number of examples will be discussed. These parts were picked out to show how this procedure was followed to arrive at a final conclusion. However, some parts of this procedure were not necessary due to previous experience which did not require repetition. Some omission will be apparent due either to the restricted nature of the item involved, lack of data, or lack of time.

Tube-Forging Assembly In a Landing Gear Drag Brace—Preliminary design of this part indicated that either arc or gas welding would have to be used. The part was originally laid out as shown in Fig. 2. Stress

calculations proved that X-4130 tubing and 4140 forgings heat treated to 180,000 pounds per square inch would be needed to carry safely the design load of 152,000 pounds. The heat treating of the assembled part as originally designed presented many difficulties. Such a shape would be difficult to quench and obtain uniform hardness due to variation in cross sectional area. Distortion and subsequent straightening also caused by the heat treatment would be excessive. The use of large heat treating jigs to prevent warpage was considered impractical.

The possibility of heat treating the component parts beforehand and assembling by means of arc welding was discussed. The problem of uniformity of hardness would be eliminated by this method as well as a large portion of the distortion. Any necessary straightening would be a relatively simple operation. It was realized that the heat treat condition in the vicinity of the weld bead would be impaired by this process. Fortunately, the greatest structural requirement was in the center of the assembly with lighter loads at the four ends. This, however, eliminated the possibility of welding the cross member after heat treating. A redesign breaking the cross member into two sections was developed. Each of these parts was designed as a forging to be bolted together in the final assembly of the part, (See Fig. 3).

This design permitted welding independently each section of the cross member to the tubing forming the legs. These parts could then be heat treated without any serious problem. The change in cross sectional area between tubing and forging was not considered serious. The end forgings could then be heat treated independently and arc welded into the assembly.

The remaining problem was the type of machined joint that would be used in the assembly of the end forgings to the tube. It is immediately apparent that the welded end of the forging must slip into the tubing. In addition to stress factors, if a standard "fishmouth" joint was used, the amount of forging base needed would add to the weight of the finished product.

The "general shape" of the end attachment is illustrated in Fig. 3. The tubing is 2⅜ × .187, X-4130-steel and the forging is 4140 steel. Stress requirements at the joint are complex, but indicate that if the tube and weld will stand 152,000 pounds axial compression load, the joint may be considered satisfactory. It was, of course, necessary to provide a factor of safety.

Conventional aircraft design dictates "fishmouth" construction to permit
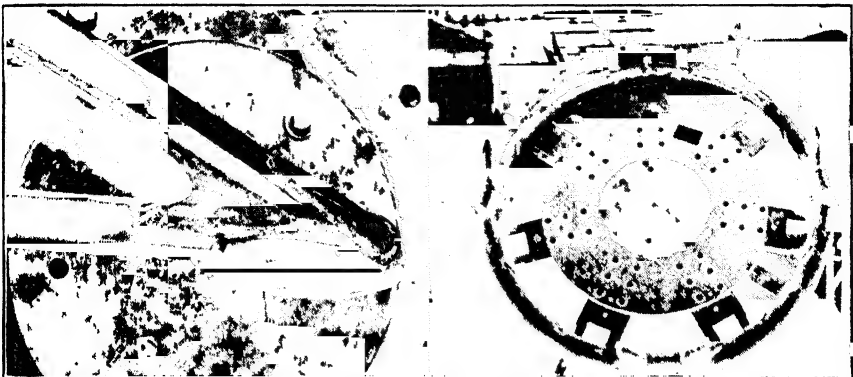
Fig. 11, (left). Leg end forging subassembly for engine mount. Fig. 12, (right). Ring subassembly for engine mount.

Table I—Test Data on Drag Brace

Item		Heat Treat Before Welding	Included Weld Angle	Type Weld	Rod Size	Penetration	Type of Fishmouth	Load at Failure	Type of Failure
No. 1	A	180,000	157.5°	Single Bead	1/8"	Hardly any in low dip of fishmouth. Weld not acceptable metallurgically	Conventional	170,000	Weld broke free of forging
	B	180,000	157.5°	Single Bead	1/8"		Conventional	172,000	
No. 2	C	200,000	135.0°	Single Bead	1/8"	Fair penetration in low dip. Entire weld only fair	Conventional type. Hand worked bottom angle	186,000	Weld broke through center of bead
	D	200,000	135.0°	Single Bead	1/8"	Better than above but not acceptable		191,000	
No. 3	E	200,000	90.0°	Double Bead	5/32" + 1/8"	Fair penetration, whole weld overlay caused large grain structure in original bead. Probably caused early failure	Conventional entire length of weld base worked by hand to 90° angle.	164,000	Weld broke through center of bead
	F	200,000	90.0°	Double Bead	5/32" + 1/8"			176,000	
No. 4	G	200,000	157.5°	Single Bead	1/8"	Shallow for entire weld length	Conventional	160,000	Ditto above No. 3
	H	200,000	157.5°	Triple Bead	2—5/32" 1—3/32"	Excellent for entire weld length	Conventional	171,000	Tube collapsed Weld OK
	I	200,000	22% 120° 78% 90°	Single Bead	1/8"	Shallow for entire weld length	Scalloped design	196,000	Weld broke in center of bead
	J	200,000	22% 120° 78% 90°	Triple Bead	2—5/32" 1—3/32"	Excellent for entire weld length	Scalloped design	211,000	Tube collapsed Weld OK

greater fillet weld cross section. A number of test "fishmouth" specimens were made up using various arc-welding procedures to determine their compression strength:

Sample 1. Two standard "fishmouth" design units as illustrated in Fig. 4a, plus the terminal forgings used in this assembly, were heat treated to 180,000 pound per square inch and then arc welded using a 1/8 inch rod with single bead weld. Compression tests were run. Welds were sectioned, etched and examined macroscopically.

Sample 2. Two standard designs as outlined above. Heat treated to 200,000 pounds per square inch and arc welded. The weld base was cut to a uniform 45° angle on the arc of the tube making an included weld angle of 135°. A single-bead weld was used.

Sample 3. Samples prepared as above except a 90° angle weld base was provided for the full length of the weld. A two-bead weld was used, the first laid in the angle and the second overlaid.

The results of these tests were somewhat discouraging, as in each case the break occured in the weld, and failure took place at loads close to the minimum requirements. It was decided to try a design never before used (to the writer's knowledge) in aircraft construction—a "scalloped edge" as illustrated in Fig. 4b. This unconventional design permitted considerably more fillet weld cross section.

Sample 4, consisted of four specimens—2 welded by single beads and 2 welded by triple beads. A complete tabulation of data and test results is shown in Table I. In addition to the gain in linear inches of fillet weld it should be noted that a fillet weld as indicated in Fig. 5a is stronger than one made as indicated in Fig. 5b where the same length of fillet weld is used in both cases. In either case, a 45° fillet breaks in the throat, and in Fig. 5b the entire load is applied at that weak point in straight shear. In the case of Fig. 5a, the actual load at the throat is the P_1 vector of the total load P. If a 45° fillet is used, then $P_1 = 0.707P$, and the strength of the joint is obviously increased. It is also interesting to note that by lengthening the horizontal leg of the fillet, it is possible to make P_1 or the shear vector smaller than P_2 or the tension vector as indicated in Fig. 5d. This immediately strengthens the weld, regardless of increase in horizontal leg.

For the purpose of mathematical calculation to indicate the amount of increase in strength, we will assume that P_1 is greater than $5/4\ P_2$ so that the weld failure will be due to tension loading. An analysis of the forces at the break indicates that P_2 is the determining factor, and since P_2 is in tension, the increase of strength in such a fillet weld in compression or tension may be shown mathematically:

if: the allowable normal stress in tension or compression equals "S"

then: allowable shearing stress equals approximately 4/5S

hence: if the safe load per linear inch of fillet of a weld as indicated in Fig. 5b is assumed to be 2000 pounds.

then: safe load of a fillet designed per Figs. 5a and 5d would be:

$\frac{2000}{\cos 0} \times \frac{5}{4}$, because the weld would break in tension through throat per P_2 vector.
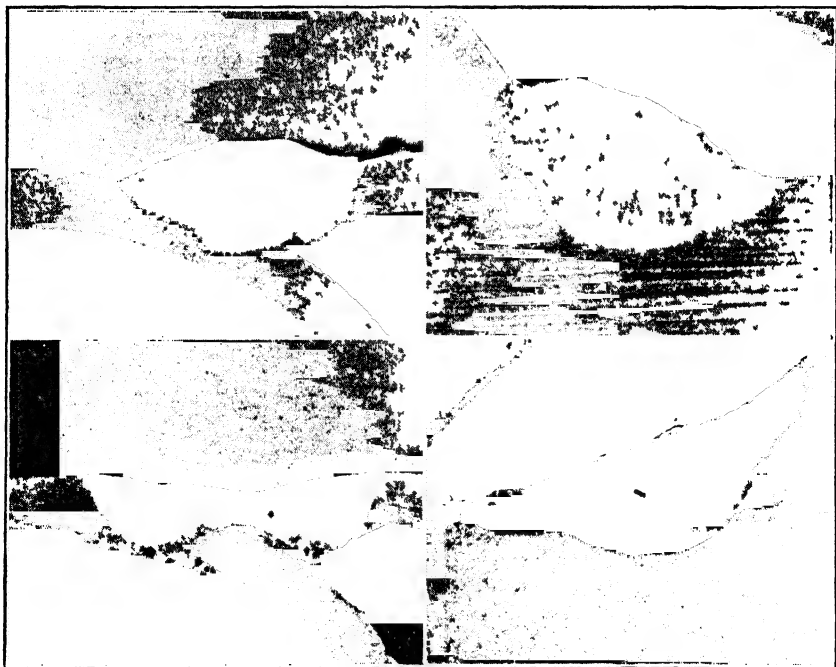
Fig. 13. Metallographic comparison of arc and gas welding, arc welding above, other method of welding below.

In computing stress, engineers are apt to use shear values for fillets in straight shear as experimentally determined by Fig. 5b, whereas the redesign to place the weld fillet as shown in 5a will result in greater strength.

Metallurgical examination of single, double- and triple-pass welds showed that a triple-bead produced the best weld characteristics The single-bead weld produced only limited penetration due to necessity of obtaining good appearance The double bead gave fair penetration, but large grain size in the first bead The triple bead weld using a larger rod for the first 2 passes, and a small diameter rod for the final pass produced a weld with good penetration, and no difficulty in obtaining a smooth outside appearance Grain size with the triple weld was satisfactory.

While a single-pass bead using large rod would result in some savings, it was not considered because of the rigid structural requirements of the part and the results of the laboratory tests. Production welding was performed with simple positioning jigs The fabrication in subassemblies reduced the jig expense and eliminated much of the warpage during welding.

Machining of the redesigned attachment end was performed on a milling machine One big advantage in this type of end joint is the presence of an approximately 90° included angle for the laying of the weld bead This permits simpler welding technique and improved penetration.

No major production problems have arisen on this assembly All parts are magnetically inspected after welding for cracks or other defects The type and size of the structure minimizes the possibility for cracks and no trouble has been experienced.

It should be remembered that this part was specifically designed for arc welding, therefore actual time-study comparison cannot be presented. However, similar joints have been gas welded with production costs definitely established by many years of experience. Based on this experience, costs, outlined in Table II may be considered accurate within ± 5 per cent.

Table II—Time and Costs of Arc Welding the Landing Gear Drag Brace

Item	Arc Welding Time	Arc Welding Cost
Joint Preparation	:10	$ .18
Welding Labor @ $1.00 per hr.	1:40	1.67
Gas Welding Rod		.83
Power Cost @ 1¢ per kwh		.05
Heat Treatment	1:00	1.10
Straightening	:30	.40
Overhead		4.23
TOTAL FABRICATION COST PER PIECE		$8.46
Savings by Use of Arc Welding		$9.30
PRODUCTION TIME SAVED		3:12

It may be wise to summarize the reasons for the use of arc welding on this part.

1. It was considered necessary structurally to use a process which would produce a minimum amount of heat. In this manner, the effect on the heat treatment of the component parts would be lessened and would make possible the use of subassembly fabrication.

2. Relatively close tolerances were required and it was felt that the arc welding process would produce less distortion than gas welding and reduce expensive straightening.

3. The "as welded" strength of the arc bead in this case is greater than a comparable gas bead. It was necessary to obtain maximum strength to provide a reasonable margin of safety.

4. From experience, it was evident that the arc process would produce a considerable time saving because of the ease of the welding operation.

Landing Gear Support Assembly—The assembly shown in Figs. 6 and 7 was originally designed with very little preliminary consideration. The assembly of this part resulted in high costs and many shop complications. Rejections were so high, due to cracking and distortion, that it became evident that a different assembly process would have to be used. It was agreed to change to arc welding. This change, however, did not solve the problems in itself and it became necessary to develop a rigid preliminary shop procedure to guarantee acceptable parts.

Because large quantities of the component parts of this assembly were already on hand, it was impossible to change the design except in minor details without incurring considerable cost and time loss. At this point, it is interesting to note that this part presented a serious production bottleneck which demanded immediate solution. Cracking along the weld beads was the paramount problem. This occurred, in most cases, in welding the end forgings to the tube and welding the interior gussets, (See Fig. 10).
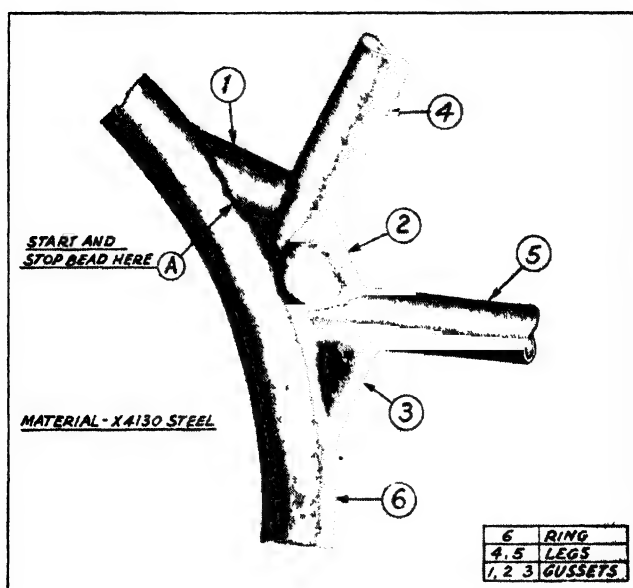
Fig. 14. Section of engine mount ring assembly showing box-type gussets.

The end forgings are 4140 steel while the tube and sheet metal parts are X-4130. Because of structural requirements, it was necessary to have the tube in the heat treated condition, while the forgings could be used without heat treatment. For the same reason outlined in the previous section, it is not practical to heat treat after complete assembly. Here again, the major load requirements are on the center of the tube (creating a torsional twist through the hole) permitting arc welding the normalized and forgings to the heat treated tube subassembly. The strength at this joint is not seriously impaired by the reduction in heat treat due to welding.

With these conditions in mind, a number of production assemblies were made. From observation the following relatively involved shop procedure was developed. The complicated procedure which is outlined serves to indicate the care necessary to overcome difficulties in welding a structure of this type. Reference should be made to Figs. 8, 9, and 10 in following through this procedure.

1. All parts of the beam subassembly are rough-filled to a loose fit.

2. The component parts of the beam subassembly are placed in the welding jig. The stiffener, bosses, clips and supports are tack welded at two places with 5/64-inch rod. The collar is tacked at four places at the small end inside the beam with 3/32-inch rod.

3. The subassembly is removed from the jig and heated to 400°F. All welding operations are made with the part at this temperature.

4. The parts are arc welded to the beam with 5/64-inch rod on the stiffener and bosses and using 5/32-inch rod for the clips, supports and collar. A definite order producing minimum cracking defects was necessary.

(a) **Stiffener.** Welding is begun between the tack welds and finished in four operations using four rods.

(b) **Bosses.** Welding is begun between tack welds. ⅘ of circumference is welded leaving the ⅕ adjacent to the collar unwelded. This section is welded when the continuous bead is welded around the collar producing better penetration and appearance of the collar weld bead.

(c) **Clips.** Weld outside of clip from one corner around the 90° bend to the opposite corner. Inside of clip is welded from edge to edge in one operation.

(d) **Supports.** Weld completely around in two operations, starting bead between tack welds.

(e) **Collar.** This operation proved relatively difficult and required close control of procedure. The small end of the collar is welded inside the beam followed by welding of the large end of the collar on the inside. The small end of the collar is welded on the outside, also, filling in unwelded portion of all bosses, all in one operation. The large end of the collar is then welded on the outside.
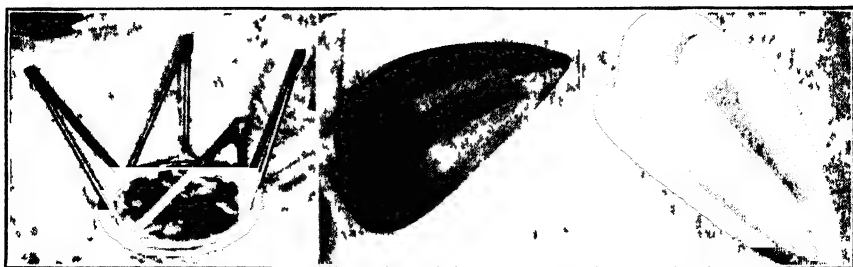
Fig. 15, (left). Arc welded engine mount assembly. Fig. 16, (center). Bottom view of exhaust gas fairing. Fig. 17, (right). Top view of exhaust gas fairing.

5. The subassembly complete except for the interior webs is buried in mica flakes and held until cool. After cooling the part is normalized to eliminate as far as possible all welding stresses.

6 After normalizing, the three webs are fitted into the assembly and tack welded to the tube Tacking to the collar tends to produce cracks

7. Assembly is preheated to 400°F. Webs are welded to the collar, afterwards welded around curvature of the tube. When welding webs around the tube, the assembly is tilted at a 45° angle and turned slowly so that weld bead is laid in a cradle positioned 45° fillet. This makes for easier welding of the webs and prevents undercutting. Assembly is positioned and turned so that welding is done on a flat or slightly vertical plane, thereby keeping slag from running ahead of the weld puddle.

8. Assembly is again cooled in mica flakes followed by sand blasting and magnetic inspection

9. If cracks are indicated, they are repaired as follows:

(a) All traces of the crack are removed with a small grinding wheel.

(b) Magnetic inspection is used to check complete removal of crack.

(c) Assembly is heated to 400°F. and repair weld made followed by cooling in mica flakes. Again, magnetic inspection is used to check the repair weld.

10. The beam subassembly is heat treated to 150,000 pounds per square inch and machined to drawing requirements.

11. End forgings and the heat treated beam subassembly are assembled

in the welding jig. As the welding tends to draw the ends of the forgings in toward the beam, a slight taper is allowed in the jig.

12. With the temperature maintained at 400°F., the ends are welded in place, and then the entire assembly cooled in mica flakes.

Table III—Time and Costs of Arc Welding the Landing Gear Support Assembly

Item	Arc Welding Time	Arc Welding Cost
Preheating	:12	$ .14
Welding Labor at $1.00/hr.		
1. Beam sub-assembly	1:00	1.00
2. End Forgings	:40	.67
Welding Rod or Electrode		.75
Power Cost at 1¢ per kwh		.05
Heat Treatment	2:00	2.20
Straightening	:30	.38
Overhead		5.19
TOTAL FABRICATION COST/PIECE		$10.38
SAVINGS BY USE OF ARC WELDING		$18.62
PRODUCTION TIME SAVED		5.3 hrs.

13. The assembly is sand blasted and inspected for defects as outlined above.

This very detailed procedure has been given to show what is required in the arc welding of complicated assemblies to give trouble-free production. Prior to the development of this assembly method, rejections were running approximately 75 percent. When complete welding control was established, rejections became negligible. Despite the involved procedure, the arc welding method produced a considerable time saving. The detailed cost and the resultant savings are indicated in Table III.

Motor Mount Assembly—No preliminary development was necessary to establish correct design or structural characteristics as this is a standard assembly which has been in use for some time with slight modifications. Tubular and sheet metal parts of the assembly are X-4130 alloy steel and the attachment forgings as shown in Fig. 11 are 4140 alloy steel. Laboratory checks of representative arc welded samples, (See Fig. 13), made by production welders indicated superior penetration and greater density with arc welding. These photomacrographs show an obvious gain in quality.

Shop procedure was relatively simple, requiring no complicated jigs, or preheating. The only joint which required careful attention is the box-type gusset illustrated in Fig. 14.

No difficulty from cracking was encountered in the first production items due to the experience developed in other mounts using this type of gusset. However it is interesting to note the procedure which was used. If gussets 1, 2 and 3 are welded in that order, with no definite procedure of starting or stopping welds, then cracks may be expected in the last (or closing) weld. When gussets 1 and 2 are welded, the residual stresses are dissipated by a slight movement of the tubes 4 and 5. However, when gusset 3 is welded, the structure is so rigid that it resists movement resulting in cracks at the weakest

points. Preheating or slight dishing of the gussets has been used to overcome this problem. However, if all weld beads are started and stopped in the middle of "flat" surfaces, such as shown at point "a" in Fig. 14, then residual stresses per unit of cross section are lessened, resulting in a minimum of cracking.*

Table IV—Detailed Time for Arc Welding the Motor Mount Assembly

Type of Weld	NO. OF WELDS	TIME IN MIN. FOR ARC Time/Piece	Time/Mount
30° angle splice welds	2	10	20
Washer-to-lug welds	28	3	84
Lug-to-ring welds	14	6	84
Double-joint welds	3	20	60
Single-joint welds	2	10	20
Box-gusset welds	9	20	180
Strip-gusset welds (in and out)	4	20	80
Oil support bracket-to-ring welds	4	10	40
Wrap gusset welds	8	15	120
Double-tube-to-fitting-joint welds	4	25	100
Plate gusset welds	4	20	80
Fishmouth splice welds	8	5	40
Lift ring-to-ring weld	1	15	15
Cowl-support-to-ring welds	4	15	60
*TOTAL IN MINUTES			983
*TOTAL IN HOURS			16.4

*Welding time only

Table V—Time and Costs of Arc Welding of Motor Mount Assembly

Item	Arc Welding Time	Cost
Welding Labor @ $1.00/hr. by Units		
1. Ring sub-assembly	11:28	$11.49
2. Leg sub-assembly	3:00	3.00
3. Mount assembly	1:55	1.94
Welding Rod or Electrode		3.17
Power Cost @ 1¢/kwh		.57
Straightening	:30	.38
Overhead		20.55
TOTAL FABRICATING COST PER UNIT		$41.10
Savings by use of Arc Welding per Unit		$104.18
PRODUCTION TIME SAVED PER UNIT		26.4 hrs.

The part is made by welding the ring and support attachments, (See Fig. 12), as one subassembly and the supports as independent subassemblies (See Fig. 11). These subassemblies were then welded in a standard jig to complete the assembly, (See Fig. 15). Previously welded mounts invariably produced more pronounced tendencies towards cracking, particularly in the box-type gussets. Arc welding, using the procedure just outlined, further reduced this trouble. This incidentally reduced inspection and repair costs which may be considered "hidden" savings.

Table IV is a detailed breakdown for the welding time only. Assembling a motor mount with arc welding results in a total cost savings per unit of

$104.18 as shown in Table V. Even with no time saving or improvement in quality, in view of the lower cost of arc welding, the continuance of the other method could not have been justified. Actually, there was a considerable time saving and quality improvement.

Exhaust Fairing—The assembly illustrated in Figs. 16 and 17 is an exhaust fairing made entirely of stabilized 18-8 steel. Design is controlled by aerodynamic and operational requirements rather than structural. It is most difficult, even with photographs, to convey the unusual complexity of the shapes of the 5 component parts.

The component parts are preformed to the desired shape and assembled in a definite order. Gas tight seams are necessary to control the flow of exhaust gases properly. Because of the relatively complicated shape and intricate design, the danger of warping or distortion during welding is evident. No change of design to minimize this condition could be developed. Arc welding was chosen as the method of assembly because it produced less heat and was a more rapid process. Starting and stopping tabs were added to facilitate high-speed production.

Preliminary examination based on previous experience and consultation with other companies making similar parts indicated that relatively elaborate jigs would be required. First consideration was given to the construction of collapsible water-cooled copper back-up blocks and holding fixtures to maintain shape and tolerances. A complete set of jigs was manufactured for this purpose. Necessarily, these jigs were rather clumsy and not conducive to high-speed production, although satisfactory results were obtained.

When the first production parts were being made, it was noticed that there was sufficient overlapping of metal sheets to permit tack assembly by the use of resistance spot welding. An experimental fairing was assembled and it developed that, by use of this method of holding the parts together, the elaborate welding jig could be eliminated. Arc welding after preliminary spotweld assembly did not result in excessive distortion when welded outside of the jig. This was due to the inherent rigidity of this particular design.

This combination of spotwelding and arc welding on gas-tight stainless steel structures presents possibilities of appreciable savings over methods generally in use for this type of assembly. The secret of this method is to incorporate sufficient rigidity into the prefabricated spotwelded assembly prior to arc welding.

Table VI—Cost and Time of Arc Welding the Exhaust Fairing

Item	Arc Welding Time	Arc Welding Cost
Spot Welding	:07	$ .08
Welding Labor	:25	.42
Power cost at 1¢ KWH		.02
Grinding	:30	.38
Straightening	1:30	1.13
Overhead		2.26
TOTAL FABRICATION COST PER PIECE		$4.29
SAVINGS BY USE OF ARC WELDING		$3.07
PRODUCTION TIME SAVED		1.06 hrs.

Table VII—Total Savings in Time and Cost on 60,000 Planes Through Use of Arc Welding

Assembly	Savings in Time & Cost on 60,000 Planes	
	Cost Savings in Dollars	Time Savings in Hours
Landing Gear Drag Brace	$ 558,000	187,200
Landing Gear Support	1,117,200	318,000
Motor Mount	6,250,800	1,584,000
Exhaust Fairing	170,400	63,600
TOTAL SAVINGS	$8,096,400	2,152,800 hrs.

This part was assembled by arc welding the two interior pieces of the tube and then assembling this subassembly with the other component parts by means of spotwelding. Arc welding of all seams is then completed. Table VI shows the savings in time and money through the use of this procedure.

As was stated at the outset, the potentialities of arc welding in aircraft construction have not been fully realized. Substantial savings in time and money, have, however, been made through its use and greater savings may be expected as its use is expanded.

Unfortunately, present war and government restructions do not permit the release of total annual time and money savings. However, if all of the arc welded assemblies discussed were used on each of the 60,000 planes mentioned in President Roosevelt's aircraft production program for 1942, the total possible savings would have amounted to $7,874,400 and 2,152,800 man hours (see Table VII) as compared to previously used conventional methods of assembly.

Chapter VII—Arc Welded Tubular Fuselage

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Subject Matter: Airplane fuselage. This paper stresses the improvements in arc welding procedure between 1940 and 1942. Welding time per fuselage has been reduced 60.3 per cent. Use of the larger electrode sizes and a proper balance between quality of weld have had an important effect. Other contributing factors include: simplification of design, use of subassemblies and use of automatic conveyor equipment.

This report on the tubular fuselage of the Vultee Valiant basic trainer is not intended to show the advantages of an entirely arc welded structure over outmoded acetylene welding methods. To do that would be to reiterate a foregone conclusion that has been proved endlessly by others. Rather, I will show the amazing progress that has been attained in the arc welding field itself.

The fuselage, (See Fig. 11), is comprised of 15 attachment forgings and bushings, 295 gussets, brackets, and fittings of 4130 chrome-moly sheet stock, ranging in thickness from .035 to .095, and 110 pieces of 4130 chrome-moly tubing. The wall thickness of the tubes and the quantity percentages of each is as follows:

.035 — 74%	.058 — 4%	.083 — 2%
.049 — 13%	.065 — 6%	.095 — 1%

Altogether, a total of 410 parts are arc welded into one integral unit.

The original engineering estimate for the man hours of welding for each fuselage is given at 100 percent. With production going into full swing in June of 1940, these figures were lowered to 72.50 percent at the very beginning. From then on, steady improvement was made to the present day low of 28.75% welding hours for a completed unit. Many factors have entered into this improvement, and I will attempt to show these factors by comparing methods used in 1940 and the present day:

1, Electrode Sizes—Rod sizes used are as follows:

1940 — 1/16–80%, 5/64–15%, 3/32– 5% of the total used.
1942 — 1/16– 5%, 5/64–45%, 3/32–50% of the total used.

The trend to increase electrode sizes was the keynote in attaining our present production rate. Procedures were changed to permit longer continuous welds, and welders were encouraged to use larger rod sizes. This, to some extent, was made possible by developing new techniques in manipulation, principally the use of more current and choking of the arc when welding on thin material.

In this manner, the operator starts with a normal arc length, shortens the arc and "rides" the rod when the parent metal accumulates excessive heat. The arc is then lengthened, shortly before intersecting another weld or upon continuing on heavier material, and vice-versa. Another important advantage in the use of larger rod was found in the welding of small parts where welds were extremely short. A 1/16 rod is good for making only two half-inch welds, whereas a 5/64 rod will do for 6 or more.

2, Subassemblies—The breakdown of the fuselage into as many subassemblies and operations as practicable has had a decided bearing on the production rate. In this manner the operator will now have from three to six jigs to rotate on in the building of a section, whereas one jig was used in 1940. This allows more accessible jigs to be constructed and circumvents any necessary waiting by the operator for the set up of parts.

3, Time and Motion Studies—Time studies have been made and put into practice for the placement of work. Thus the welders have the correct number of different subassemblies to build or operation to perform on the main frame to make a standard work day. Motion studies have resulted in the use of fast operating electrode holders and the elimination of a goodly portion of slag removal by hand. The balance is taken care of in the final sand blasting operation.
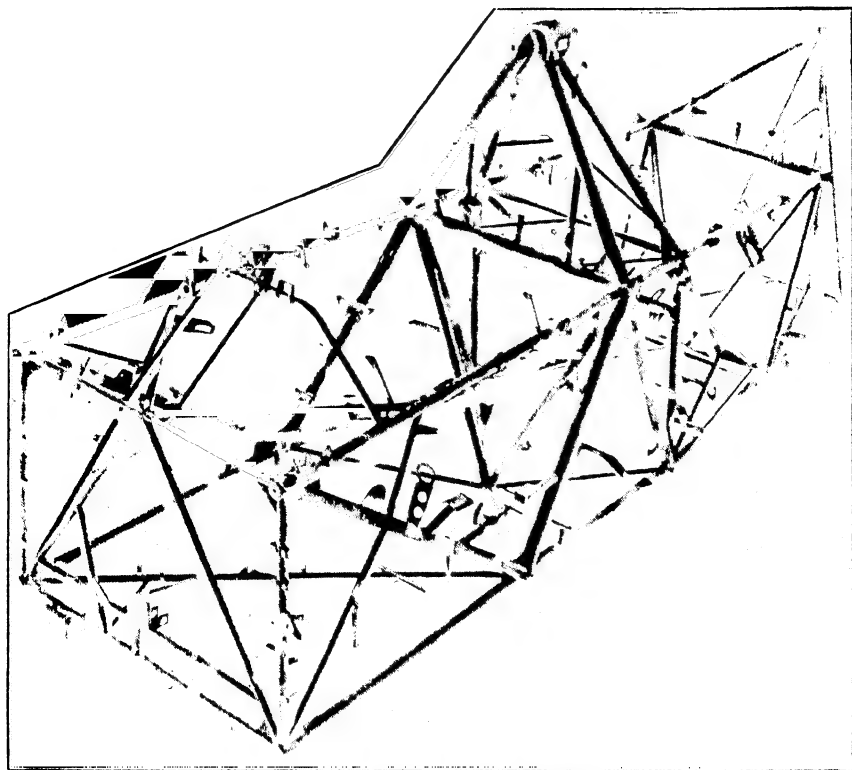
Fig. 1. Arc welded tubular fuselage.

4, Conveyor Equipment—Vultee has, to the best knowledge of this writer, the first powered, automatic conveyor line for aircraft welding. This has eliminated much of the time formerly lost in advancing the stations by hand, with resulting confusion of welding cables, relocation of ground cables, and other equipment.

5, Ratio of Quantity to Quality—This has been one of the outstanding problems encountered by supervision and management and one of the strongest factors in utilizing the superior speed and strength of arc welding. At the start of production, emphasis was made on appearance. This, no doubt, was a carry over from the day of the hand made airplane. Our job, therefore, was to prove that arc welding applied at a rate conducive to high speed production might be uneven and at the same time surpass specifications for strength. When this was proved, we had only to level off at the correct quantity-quality ratio for the most profitable results.

6, Simplicity of Design—As previous welding was done with acetylene and little consideration was given quantity production, the "Valiant" fuselage was at first a very intricate design. With the introduction of arc welding, the need was soon apparent for simplifying the structure. For example, one large tube was substituted in place of several small ones, and one bracket was redesigned to do the work of two or more. Another important point was gained by increasing the edge distance of sheet stock parts to permit the operator to weld with speed and ease without burning the edges.

The results of the foregoing factors may be seen in the following figures:

	Man hours of welding	Cost per unit	
1940	100%	*	100%
1942	40%	*	39.47%
Savings	60%	*	60.53%

*(Based on an average hourly rate of $1.10)

As the number of men necessary to weld one fuselage has been more than cut in half, hidden savings must also be taken into consideration, not only in dollars, but in precious manpower and material for the all out war effort. If twice the number of men were needed, we would be compelled to double the amount of tooling and floor space.

Although the total amount saved through the use of arc welding in the past two years is meritorious, conversion of these savings into figures at this time would give a clue to the Vultee warplane production rate and must, therefore, be withheld.

As we look to the future, we know that arc welding will continually add to the efficiency of aircraft manufacture as it has in the past. New, perfected electrodes, procedures, and improved equipment will guarantee this, and arc welding will prove a vital factor in the all out production effort needed for victory. With the coming of peace, new and greater fields will open for our craft, and arc welding will become as effective a tool for the peace-time aircraft industry as it has become during the war.

SECTION III

Railroad

Chapter I—Arc Welded Diesel-Electric Freight Locomotive

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Subject Matter: Problems involved in the construction of an all welded 5400-horsepower diesel-electric freight locomotive and the successful resistance of welded carbodies to temperature of the oven of 7–60°. A general description of the locomotive is given together with references to the successful performance of this type. Favorable comparisons of weight and tractive force with steam unit constructed along conventional lines are made. Detailed discussion of major assemblies, including the all welded car body, underframe front and rear end framing, side frames, outside paneling, etc., follows. The power plant is also described and welding techniques employed, detailed, together with the effect of weld metal in flux density, and the magnetic reactions of highly sulphurized steels used as generation frame material to reduce machining time. Operating advantages are pointed out.

Since the fateful day of Pearl Harbor, all branches of modern transportation in the United States have been overwhelmed with a volume of passenger and freight traffic hitherto unknown in the annals of industrial progress in any country. Every phase of the three principal types of transportation services was affected by the impetus of these events: Aerial as well as maritime cargoes have overnight reached unbelievable proportions, while America's railroads were at the same time expected to haul not only scheduled trains, but to move troops and defense materiel commensurate with the nation's determined war efforts. This job required the utmost
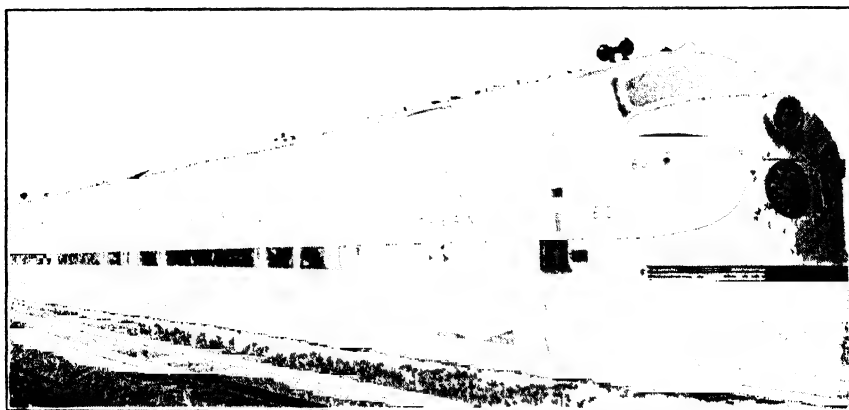
Fig. 1. 5400-horsepower 4-unit locomotive ready for service.

in tonnages to be moved, speeds to be maintained besides greatest versatility of motive power, which combined requirements simply could not be expected of the available conventional steam engines

The Diesel-electric streamliners in passenger service have made history by their faithful gruelling mileages accumulated daily at high-speed schedules over practically all leading railroads, while the same kind of motive power has very definitely proved its operating economies in continuous yard-switching service This superiority over steam locomotives spurred the efforts towards the development fo such power equipment, which could develop the highest possible tractive effort and attain speeds up to 70 or 75 miles per hour—and do it economically for nearly 24 hours a day, seven days per week In order to achieve this goal, all operating experiences were scrutinized before a definite design and ultimate construction of the first "universal" Diesel electric freight locomtive became realities The initial units were admittedly experimental, but improved production locomotives were built and delivered in considerable numbers within the year, which have received immediate endorsements by the railroads, and which have warranted an A 1-A priority rating by the war production board for their significance in defense transportation
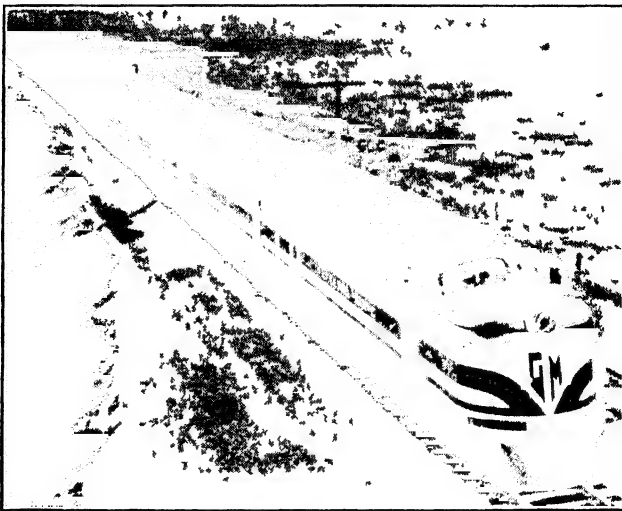
Fig. 2. The first 5400-horsepower Diesel-electric freight locomotive on trial run.

Material Considerations—In the early stages of development, it was readily evident, that a fully utilitarian high-speed freight locomotive of the Deisel-electric type must operate under any atmospheric conditions, ranging from some 120° above to as low as 40° and perhaps even 60° below zero. Actual surface temperatures of locomotives used in Pacific and southwestern desert areas were recorded to unbelievably high values, but, metallurgically, greater concern must be expressed over the resistance of various materials to impact stresses at very low temperatures Some doubt has been voiced by adherents to conventional steam power as to the importance of low temperatures in actual service conditions. Perhaps the high percentage of castings together with the heavy masses required in their construction are the major reasons for this attitude. Recorded experiences of northern and

western railroads with steam locomotives indicate definitely a higher frequency of material failures in extremely cold weather. In contrast, not one failure of this origin has ever been reported with welded car bodies nor welded crankcases after more than 100 millions cumulative mileages on high-speed Diesel-electric streamliners. In order to justify this consideration, the author has made a study of prevailing low temperatures in those territories, where Diesels are expected to render uninterrupted service. This task included preparation of a survey from the records of the U. S. Weather Bureau by compiling the lowest temperatures of the arbitrarily selected years of 1900, 1910, 1920, 1930 and 1940. The table below summarizes these figures:

U. S. Weather Bureau Station at	Railroad Service by	Lowest Temperatures in Degrees Fahr. for Year					All Time Lowest °F.
		1900	1910	1920	1930	1940	
Duluth, Minn.	Gr. Northern No Pacific Soo Line	−22	−22	−25	−28	−22	−41
Hallock, Minn.	Gr. Northern	−37	−39	−39	−44	−31	−51
Moorhead, Minn.	Gr. Northern	−26	−28	−35	−29	−23	−48
Eau Claire, Wis.	Chicago & N. W.	−23	−32	−30	−30	−21	−40
Williston, N. Dak.	Gr. Northern	−41	−40	−37	−28	−26	−49
Bismarck, N. Dak	No. Pacific	−33	−37	−32	−28	−26	−45
Kalispell, Mont.	Gr Northern	−19	−22	− 8	−23	− 7	−34
Miles City, Mont	Milwaukee	−16	−29	−31	−31	....	−49
Pocatello, Idaho	Union Pacific	−15	−15	− 3	−22	− 2	−22
Lander, Wyo.	Colo. & Southern	−30	−32	−19	−39	−23	−40
Yellowstone, Wyo.	Union Pacific Colo. & Southern	−25	−20	−25	−34	−42	−42
Cheyenne, Wyo	Union Pacific	−18	−10	−14	−30	−19	−38

The above official minima for the stations mentioned were exceeded in 1936 by temperature readings down to 60° below zero in Riverside, Wyoming, within the Rocky Mountain region. It is interesting to note, that only Diesel-electric equipment maintained railroad operations, while steam locomotives simply froze up. Similar experiences have been freely admitted by operating personnel in other sectors as far south as Nevada. It is felt, therefore, that the selection of materials, joints and auxiliary equipment for highly available motive power units should make allowances for decreases of impact resistance to as low as 60° below zero. This thought has been incorporated into the engineering and control tests of all important parts of the new locomotive with fully accountable returns in safety and availability for all atmospheric eventualities.

General Description of the Locomotive—Looking back upon the frequently cited steam monsters as the 2-10-10-2 locomotive of the Virginia Railroad or the 2-8-8-4 freight locomotive of the Northern Pacific, the new E-M Diesel-electric locomotive represents a decidedly radical departure. This is true in regard to external appearance as well as to the construction of its power plant and other mechanical equipment. A sketchy general description of the many innovations from time-honored practices will shed

the first light upon the many reasons why welding was utilized so generously in the assembly of the final product.

The "locomotive" is actually a multiple of four "units" so designed that all may be operated from control stations in the engineers' cab of the streamlined nose of the leading or both ends. The first alternative (with one streamlined unit only) permits road operations in but one direction, whereas, the adoption of units with control cabs on both ends (that is, the first and fourth unit) eliminates the necessity of turning the entire locomotive at the terminal. Fig. 1 shows the second possibility. Both are rated at a total of 5400 horsepower. The units or sections are ordinarily known as cab unit, A, B and C sections. Each unit or section is powered with a 1350 horsepower Diesel engine of General Motors two-cycle type, which engine is directly coupled to a 600 V direct-current generator in addition to a three-cylinder, two-stage Gardner-Denver air compressor.

Fig. 3. Side view of carbody before installation of equipment and paneling.

The generator of each unit supplies electrical energy to four type D-7-k direct-current motors also developed and built in the shops of Electro-Motive. The potential economy of multiple units is evidenced from advantageous flexibility over ordinary steam power Thus, it is possible by a few uncoupling manipulations to change the large 5400-horsepower locomotive into a single 1350-horsepower, double or 2700-horsepower, and triple or 4050-horsepower combination. This advantage is rarely of interest in these days of exceedingly heavy traffic, but it will undoubtedly become a feature when normal freight schedules are resumed. It appears, that the two-cab 5400-horsepower combination has some attraction, because it is easy to split the same into two 2700-horsepower units or a 4500-horsepower and one 1350-horsepower plant, both furnishing motive power to two trains.

If a railroad operates two or several complete locomotives, still other combinations are feasible, thereby adjusting motive power efficiently to vary-

ing traffic conditions without sacrificing mobility of each unit. Inasmuch as the nominal maximum speed can be raised to a rated top speed of 80 miles per hour, such split units may haul heavy freight tonnages at relatively low speeds, while the balance may operate without even a simple adjustment in passenger service.

These reasons together with the remunerative operations and mechanical ease of control were certainly some of the reasons for the immediate response especially by those railroads, which did anticipate operating difficulties:

Table I—E-M Diesel-Electric Freight Locomotives Delivered in 1941 and 1942

Purchaser	R. R. Locomotive Serial No.	Month and Year of Complete Delivery	Number of Units		Total H.P. per Locomotive
			With Cab	Without Cab	
Southern Railway	6100	May — 1941	2	2	5,400
	6101	July — 1941	2	2	5,400
Great Northern Ry.	5700	May — 1941	1	1	2,700
	5701	June — 1941	1	1	2,700
	5900	Oct. — 1941	2	1	4,050
Chicago, Milwaukee, St. Paul & Pacific	40	Oct. — 1941	2	2	5,400
Western Pacific	901	Nov. — 1941	1	3	5,400
	902	Dec. — 1941	1	3	5,400
	903	Jan. — 1942	1	3	5,400
Denver & Rio Grande Western	540	Jan. — 1942	1	3	5,400
	541	Feb. — 1942	1	3	5,400
	542	Feb. — 1942	1	3	5,400
Atchison, Topeka & Santa Fe	100	Aug. — 1941	1	3	5,400
	101	Aug. — 1941	1	3	5,400
	102	Sept. — 1941	1	3	5,400
	103	Sept. — 1941	1	3	5,400
	104	Nov. — 1941	1	3	5,400
	105	Mar. — 1942	1	3	5,400
	106	Mar. — 1942	1	3	5,400
	107	Apr. — 1942	1	3	5,400
	108	Apr. — 1942	1	3	5,400
	109	May — 1942	1	3	5,400
	110	May — 1942	1	3	5,400
	111	May — 1942	1	3	5,400
	112	May — 1942	1	3	5,400
Total as of May 31, 1942			29	66	128,250

Table I summarizes the first "educational" orders placed by several railroads, after the original 5400-horsepower demonstrator operated 83,764 miles on twenty Class 1 railroads in 35 states under all imaginable conditions, that is, from sub-zero to 115° above, as well as from sea level to 10,000 feet elevation. Although these performances surpassed any riveted
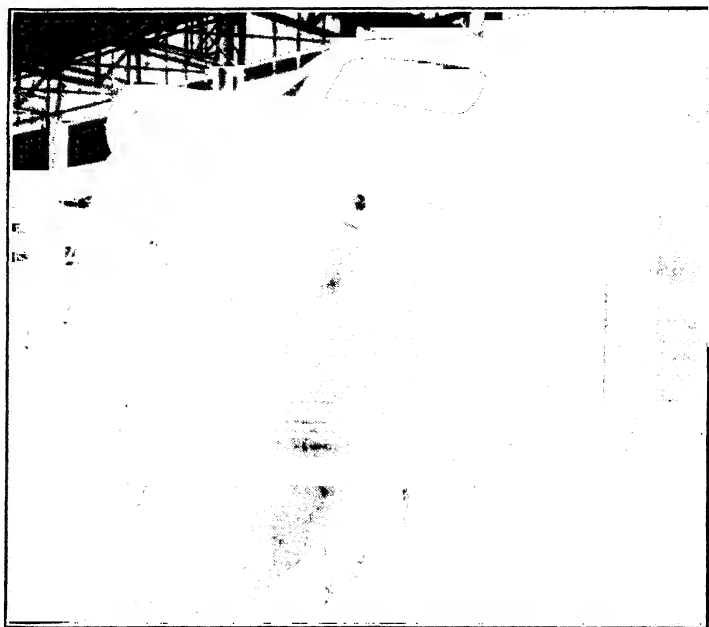
Fig. 4. The nose of the cab unit after welding.

Fig. 5. Inside view of carbody.

and cast steam locomotive thus far built, the fundamentals governing the all welded construction of the new Diesel-electric included more power and actually less weight for the complete four-unit locomotive.

This is best demonstrated by a comparison of the complete 5400-horse-power combination and a 2700-horsepower split on the basis of tractive effort (in pounds) versus speed (in miles per hour). Analysis of this problem indicates, that the starting tractive force of the new four-unit combination, (See Fig. 2), is 220,000 pounds, while such famous monsters as the Northern Pacific's freight steam locomotive was rated at 153,300 pounds and weighing 1,116,000 pounds against 923,000 pounds for the Diesel. Simple mathematics prove, that the latter weighed 17.3 per cent less than the steam locomotive, with an increase of 43.4 per cent in tractive force. Some additional information on the dimensions, weights and capacities are tabulated below:

Number of units	4	
Total length	193 ft.	
Max. width over posts	9 ft.	10 in.
Max. width outside grabhandles	10 ft.	7 in.
Height above rails	14 ft.	1 in.
Number of wheels per unit	8	
Wheel diameter		40 in.
Rigid wheel base of trucks	9 ft.	0 in.
Weight of cab unit, completely loaded	230,000 lbs.	
Weight of units without cab, completely loaded	228,500 lbs.	
Fuel oil capacity per section	1,200 gals.	
Lubricating oil capacity per section	185 gals.	
Cooling water capacity per section	245 gals.	
Boiler water capacity per section	600 gals.	
Sand capacity per section	16–22 cu. ft.	

The All Welded Carbody—Static and dynamic loading of the carbody of each locomotive unit is based on principles governing modern bridge
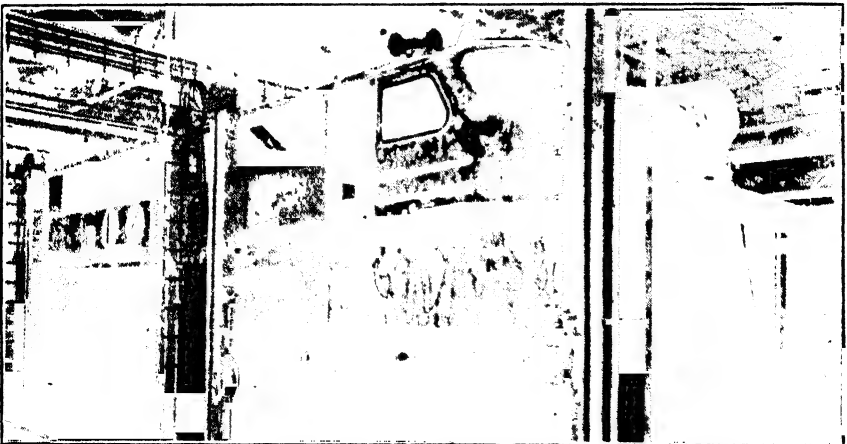
Fig. 6. Building the cab unit of the 5400-horsepower freight locomotive.

construction. Supported in two geometrical planes through the centers of the bolsters—this distance being 27 feet 3 inches—the design of the framework approaches somewhat the construction of the already-mentioned Diesel-electric streamliners. Working stresses dictated several deviations and thus the carbody is not only shorter but appears to be sturdier and less "elastic". The smooth riding properties of the high-speed passenger units have been an incentive even in the engineering of the freight units. The new units are equipped with substantially a very similar type of helical and elliptic springs, which are intended for comfort to the operating personnel.

The design features are shown in Fig. 3 which illustration gives some conception of the major parts of the carbody framework This "skeleton" may be used in the making of an A, C or D unit, that is, without a cab. The latter is shown in Fig. 4 as a semi-finished front portion of the locomotive.

Fig. 7. The all welded roof hatch.

The principal parts of the carbody are prefabricated and consist of: (a), underframe construction. (b), front end framing. (c), rear end framing. (d), side frame, left. (e), side frame, right. (f), roof framing. (g), roof hatches; and (h), outside paneling.

(a) **Underframe**—All major mechanical equipment—like the powerful Diesel engine, the generator, the compressor, etc.—is mounted directly to the underframe. A view of the upper side of this frame is presented in Fig. 5. The loads are carried primarily by a center sill, side sills and other suitable supports. In addition to these loads considerable weight is brought about by rather large, also welded, tanks for fuel oil and water, which are ultimately integral parts of the frame. A ¾-inch bottom plate in front and in the rear of the base adds, of course, to the rigidity of the quite intricate structure. Before final assembly, substantial coupler pockets are welded to both ends of the underframe.

(b) **Front end framing**—Streamlined appearance has become a recognized symbol of many modern products of our industries. From cars to locomotives, this requirement combined with economical performance are standards demanded today by private purchasers or directorates of the largest railroads. In recognition of this demand, the leading front, (or sometimes even the last), units of the new freight locomotive have been arc welded so as to resemble the now popular "nose" of the Diesel-electric

"streamliners" or high-speed passenger units. As a safety feature, the external smooth surface of 11- or 12-gauge steel sheet is supported by a very massive construction. Collision posts of 5-inch x 1½-inch cross section are securely welded on both ends into the structure. Stiffening angles and channels, made of 7-gauge steel plate, are welded wherever necessary, which together with a sturdy base plate assure anti-collapsing deformation if a front end collision should occur in service. Most of the welded joints are 5/16-inch for the stiffeners, but ½-inch for the heavy collision posts in order to assure secure fastening.

The actual operating controls center around a roomy engineers' cab (See Fig. 6), which is built somewhat over the front bolster. Of all sections of the four units, it has been given intentionally the highest floor level above the rails, thus affording maximum visibility for safe handling on the road. The operator has easy access to a controller, reversing lever, brake equipment, light switches and all indicating instruments from his comfortable seat on the right side of the room. The cab is so designed, that its floor supports together with front bulkhead and partition framework add considerable strength to the nose structure.

Fig. 8. Trucking the cab unit.

A few remarks may be added on the final sheet covering: the carefully-hammered front sections of steel sheets are plug-welded from the inside and all joints are finally covered with continuous butt welds. Grinding of these beads and expert polishing of the curved surfaces is the subsequent preparation for paint application. Great care and judgment are prerequisites for these operations. Fig. 4 shows one of the latest cab units just before transfer to the paint shops.

(c) **Rear end framing**—Except for the cab front, all other ends of the two or three units are identical in design. The same is true of the opposite ends of the cab units. The anti-telescoping principle was embodied into the original layouts. Thus a 13-inch wide and ⅜-inch thick plate and zee together with strong end angles and inner posts provide for good impact resistance in case of accident. All materials are, of course, considered in the light of shock resistance at very low atmospheric temperatures.

(d) and (e) **Side framing**—The principal parts of the side framing,

which is naturally of either left or right design, are best described by referring again to Fig. 3. The load carrying high tensile bolster posts are 6-inch by 6-inch H-beams, whereas intermediate posts and important diagonals or horizontal braces are 4-inch by 4-inch H-beams. Various stiffeners are again added to serve as supports for the side paneling and for some mechanical equipment and piping on the finished inside of the car body. The mentioned beams are welded with high tensile electrodes to the underframe and the outside ground flush after shot blasting the entire assembled structure. This permits the convenient application of smooth panels directly to the framework, as shall be described in paragraph (h).
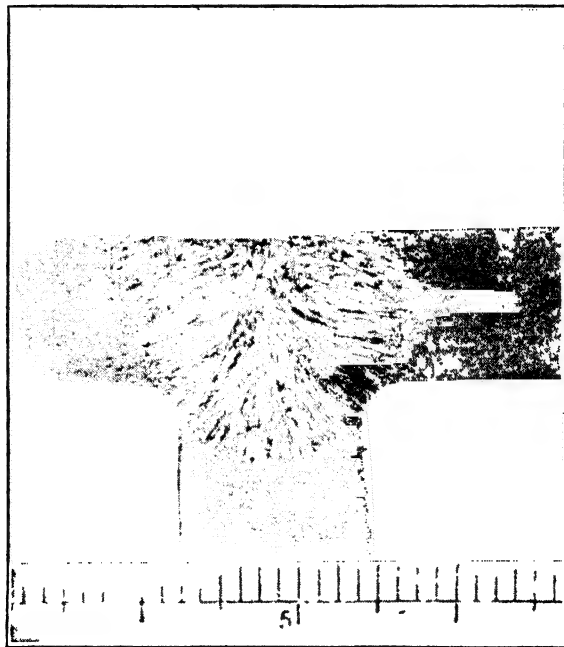
Fig. 9. Macrograph of automatically welded T joint in engine crankcase.

(f) **Roof framing**—The upper part of the end and side framing is held in place by a series of lateral roof beams and roof sheets with ample provisions for the subsequent placing of the roof hatches, the openings for which indicate that the roof framing is actually a multiple stress carrier besides being a support to essential grids, etc.

(g) **Roof hatches**—All large machinery or equipment—such as the Diesel engine, main and auxiliary generators, compressor, oil cooler, etc.—is installed into the finished car body through the rectangular openings in the roof. After this installation, the openings are covered with suitable hatches, (See Fig. 7). These are all welded assemblies, but they are bolted to the roof, thus permitting convenient removal of some of the major equipment in case of necessary inspection or repair.

(h) **Outside paneling**—A very desirable outside finish for the flat portions of the carbody has been found in the utilization of large panels of so-called metal-covered plywood. The cross-sectional characteristics of a typical ⅜-inch panel used on the sides of the locomotive are 27-gauge gal-

vanealed sheet over three-ply boards, all held together with a very strong bond of glue. In manufacture, the wood is thoroughly dried and then covered with the metallic sheet all over, the edges being hand-soldered so hermetically as to keep all moisture out. The carefully inspected panels are bolted to the flat outside of the welded carbody structure by means of 2-inch-wide, 1/4-inch-thick battens, the space between two adjacent panels being filled with a special never-drying asphaltic putty. No corrections are permitted on any of the panels for reasons stated above—they just have to fit or they are rejected. This type of paneling has been found to be highly satisfactory and welding processes have permitted the advantageous use of otherwise prohibitive designs. Riveted or bolted structures could obviously never produce the smooth "streamlined" finish of the sides of the new multi-unit locomotive. The paneled watertight carbody is manually degreased and immediately protected by a coat of special priming paint. The thus-prepared carbody is lifted from its supporting pedestals over the two trucks, (See Fig. 8), and after making all electrical and flexible connections moved into the paint shops. There the final decorative effects are sprayed on the various parts of the unit together with the designations of railroad, locomotive number, etc.

Motive Power Plant—As indicated in the general description of the locomotive, electric current is generated by power from one 1350-horsepower 16-cylinder General Motors Diesel engine of the 2-cycle type in each of the four locomotive units. The engines are known as Model 567, are of the V-type, have solid unit injection and high compression with medium speed. The engine data is as follows:

Energy output	1,350	H.P.
Number of cylinders	16	
Number of exhaust valves per cylinder	4	
Diameter of crankshaft	7.5	
Diameter of crankpins	6.5	
Number of main bearings	10	
Compression ratio	16:1	
Bore, diameter	8.5	in.
Stroke	10	in.
Starting speed, max.	100	r.p.m.
Idling speed	275	r.p.m.
Max. governed speed	800	r.p.m.
Total displacement	9,079	cu. in.
Weight of engine, approx.	30,000	lbs.
Weight per H.P.	22.2	lbs.

The principal parts of the engine are built into a comparatively light all welded crankcase weighing, finished machined, about 8,750 pounds, which is bolted to a supporting oil pan. In comparison with cast crankcases of competitive Diesels, weight reductions ranging from 58 to 80 per cent have been achieved by a series of systematic developments in the design of the case until the one shown has been adopted in the latter part of 1941. The material used is predominantly one of high-tensile low-alloy plate of 1/2- to 5/8-inch thickness, for which the typical metallurgical properties are given in Table II.

The Crankcase—The crankcase is 146.25 inches long and is built of prefabricated parts such as the airboxes, bearing supports, lift hooks, etc.

All joints are made by either automatic or manual welding. The automatic process is utilized in making the specific T-joint of the airboxes, which otherwise could not be accomplished by manual procedures. Its adoption was based on the studies made by the writer since early in 1936 on the high

Table II—High-Tensile Low-Alloy Plate of Welding Quality

Type of Plate	Manganese Molybdenum	Chrome Zirconium	Nickel Chrome Copper
Chemical Composition:			
Carbon, per cent	0.15	0.13	0.12
Manganese, per cent	0.85	0.68	0.88
Silicon, per cent	0.24	0.90	0.40
Phosphorous, per cent	0.018	0.023	0.015
Sulphur, per cent	0.017	0.027	0.022
Nickel, per cent	....	0.13	0.55
Chrome, per cent	....	0.50	0.68
Molybdenum, per cent	0.48	0.20	....
Zirconium, per cent	....	0.14	....
Copper, per cent	....	0.09	0.63
Physical Properties:			
Tensile Strength p.s.i.	75,200	74,350	82,200
Yield Point p.s.i.	46,140	51,300	54,800
Elongation in 2", %	....	37.5	31.5
Reduction of area	58.9	69.2	58.8
Rockwell Hardness	B83	B83	B83
Bend test	180	180	180
Low Temperature Shock Resistance (Charpy), in. ft. lb., at plus 75°F.	47	66	51
plus 50°F.	47	....	....
plus 25°F.	44	66	42
0°F.	36	60	38
minus 25°F.	20	....	35
minus 50°F.	24	53	30
minus 100°F.	18	39	10

volumetric penetration of the welding process. By studying many hundreds of experimental and production welds, it has been found that for low carbon steels some 140 to 220 per cent of parent metal is molten on the basis of 100 per cent added welding rod metal for most butt welds and many fillet welds. This finding was developed into the T-joint, the cross-sectional macrograph of which is shown in Fig. 9.

This joint is welded in the position shown and the upper ½-inch plate of high tensile steel is tightly clamped to the vertical ⅝-inch plate of the same material. The direction of welding is from the upper side, the electrode being vertical or perpendicular to the upper plate. In order to produce the horizontal outline flush with the plate, a very carefully planned preparation is needed prior to welding. This is accomplished by machining a ¾-inch wide and $\frac{5}{16}$-inch deep groove on the upper side of the plate. The area measures 0.235 square inches and the total area of the complete weld 0.590 square inches, thus indicating a volumetric penetration of 151 per cent. The fillets shown are maintained by solid or water-cooled copper bars fitted tightly into the 90° corners. The welding procedure is as follows:

Intensity of current, Amps	1300
Voltage	30
Current imput, KW	39
Speed of welding, in per min	13
Diameter of electrode, in	5/16

Practically no corrective measures, such as chipping or grinding, are necessary since the top of the weld is flush for all practical purposes The balance of the joints are made by using a nominal 0 50 per cent molybdenum electrode In production, positioners of two types are used in order to permit down-hand welding One simple device moving the case along the longitudinal axis and another positioner which enables the operator to place any joint into a nearly horizontal direction by utilizing two 180° segmentary worm gears operating perpendicularly to one another This principle follows the trends of modern welding as well as the War Production Board approved conservation of hard to-get alloy electrodes The operators use 3/16-inch and 1/4-inch diameter electrodes at 160 to 280 amperes for most applications and good welds have been consistently obtained After careful visional examination and dimensional checking by qualified welding inspectors, the crankcase is stress relieved in a 75-foot by 10-foot by 9-foot gas-fired furnace The thermal cycle consists in a 6-hour heating to 1200 to 1225°F, soaking at temperature for 3 to 4 hours, followed by a slow cooling to 300°F before removal The case is shot blasted and ready for machining The finishing involves the use of many highly specialized production machines, the description of which is outside of the scope of this paper
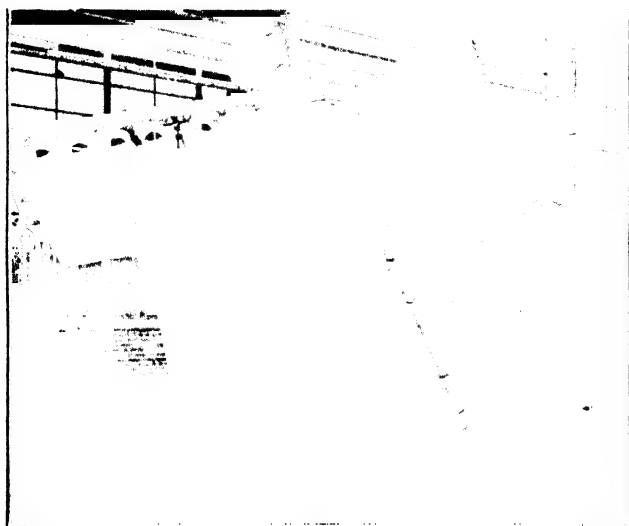
Fig. 10. Two oil pans on manipulator during welding.

The Oil Pan—In the described Diesel engine, the oil pan, (See Figs. 10 and 11), serves primarily as a base for the engine into which pan an oil sump is built. This assembly supports only static loads, for which reason 0.15 to 0.23 per cent carbon steel suffices. The engine crankcase rests on two top rails 2 5/8-inches wide by 1-inch thick which are welded to a 5/16-

inch side plate and ¾-inch end plates respectively. The oil sump is fabricated from cold bent ¼-inch plate, which is welded into the structure as indicated. Horizontal positioners are also used by the operators and electrodes for down-hand work have been adopted for this quality welding. Little distortion has been experienced during these operations. All outside welds are ground flush to give smooth appearance. All welds of the sump must, of course, be oil tight. The length of the completed oil pan is
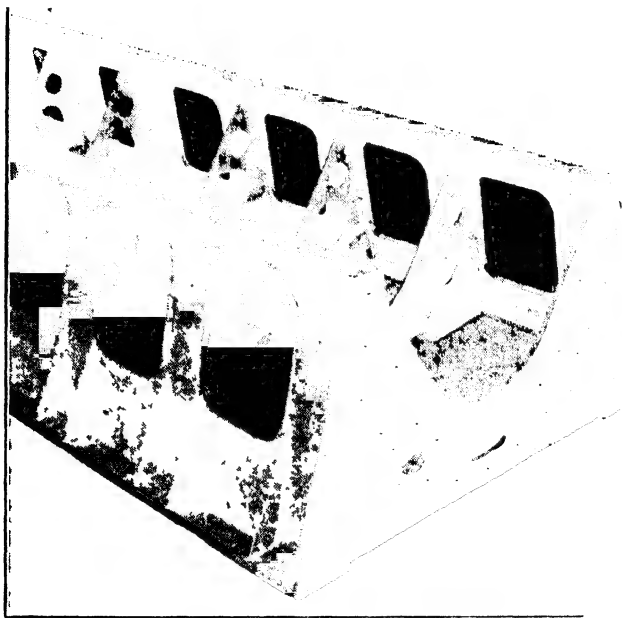
Fig. 11. End view of all welded oil pan.

determined by the crankcase it supports, hence being 146.250 inches plus or minus 0.005 inches. The weight conforms to the expected reduction from the bulky cast bases down to about 1750 pounds finished and ready for installation into the locomotive.

The Welded Main Generator—As indicated in the introductory paragraphs of this paper, the greatest part of energy produced by the Diesel engine is transmitted to the generator, both being integrally connected by a flexible coupling. Thus the generator produces the D.C. current for energizing the four traction motors of each unit, and its purpose is, of course, vital to the satisfactory operation of the locomotive. The design and ultimate operating features are hence equally important and a description of its main frame assembly may be an index of the returns in operating profits derived from the application of welding in the manufacture of this part of the locomotive's motive power.

The finished generator frame consists primarily of a continuous steel ring 25 inches wide, 50¼ inches inside diameter, which latter dimension must be accurate within plus or minus 0.002 inches. This accuracy is prompted by the interpole and field coils, which are bolted to the frame

from the outside Careful planning of operations has been worked out in order to achieve this requirement Accordingly, the frame is fabricated from a plate 26-inches wide, about 172-inches long and 2⅛-inches thick. The material must satisfy low magnetic losses as well as fairly high static strength. Both somewhat contradictory specifications are met by an intermediate analysis of which the following is a typical example.

Carbon	0 11 per cent	Phosphorus	0 008 per cent
Manganese	0 54 per cent	Sulphur	0 018 per cent
Silicon	0 01 per cent	Copper	0 17 per cent

This plate, weighing around 2695 pounds, is cold-shaped to approximate a rough ring of 54 inches outside diameter plus or minus 1/16-inch The two ends of this ring are subsequently flame-beveled for automatic welding on the inside and outside of the plate The joint is made under conditions indicated below

	Outside Weld	Inside Weld
Number of passes	1	1
Intensity of current, Amps	2400	1200
Voltage	55	35
Speed of welding, in per min	6 5	4
Diameter of electrode, in	¼	7/16
Width of bevel, in	⅞	¾
Depth of bevel, in	⅞	¾

After careful inspection for complete penetration, the ring is clamped to a positioner and the two legs applied by down hand welding These legs consist of a flat piece of steel measuring 23 inches by 8¼ inches by 1⅜

Fig. 12. Macrograph of automatic weld on generator ring.

inches. Four equally space ⅞-inch thick supports are then welded completing the leg assembly. The 0.13 to 0.16 per cent carbon electrodes are of 5/16- and ¼-inch size, currents varying from 180 to 220 amperes. Four pads are welded on top of the ring into which 1¼-inch holes for lifting lugs are tapped during machining. Before any mechanical operations are performed, the rough frame is carefully stress relieved by 6-hour heating to 1200 to 1225°F., soaking four hours at temperature and slow cooling to 300°F. in the furnace. The frame is removed, shot blasted and finally machined.

Tests were made with this material in order to study the effects on flux density at various magnetizing forces, which indicated that the all-weld metal showed only very slight variations from the ring material, thus confirming that this method of construction was definitely superior to the previously used castings, which indicated consistent magnetic non-uniformity.

Perhaps one additional possibility of modern metallurgy may be mentioned here since it offers great economies if further developed. The described method of automatic welding led the author to experiment with the use of highly sulphurized steels (up to 0.250 per cent S) as generator frame material. This was especially tempting because preliminary tests indicated 38 to 50 per cent less machining time for this modified analysis as compared with material of identical carbon concentration, but without sulphur. The prime consideration of magnetic reactions was investigated and the following figures obtained with 0.09 and 0.15 per cent carbon steels of both types.

Magnetizing Force "H" in Gilberts per cm	Flux Density "B" in Kilogausses for 0.022% S Steel with	
	0.09% C	0.15% C
10	13.3	11.4
20	14.8	13.9
40	16.3	15.6
60	17.2	16.5
80	17.8	17.1
100	18.2	17.5
120	18.6	18.0
140	18.9	18.3
160	19.2	18.6

Magnetizing Force "H" in Gilberts per cm	Flux Density "B" in Kilogausses for 0.244% S Steel with	
	0.09% C	0.15% C
10	12.0	10.8
20	14.7	13.6
40	16.4	15.5
60	17.4	16.3
80	17.9	16.9
100	18.2	17.3
120	18.5	17.7
140	18.8	18.0
160	19.0	18.4

An actual macrograph of one of the welds is reproduced as Fig. 12. The conditions under which the two welds were made are:

Size of Weld	Large	Small
Width of bevel, in.	1 8/16	3/4
Height of bevel, in.	7/8	1/2
Diameter of electrode	7/16	1/4
Intensity of current, Amps.	2100	1200
Voltage	50	35
Speed of welding, in. per min.	8.8	10.0

Unfortunately, the experiences with automatic welding were not duplicated by manual operations. The controllable slowing up and puddling of the automatic process could not be attained consistently by available electrodes, but even so, some twenty of the generators have already been successfully tested and no differences were noted between the electrical efficiencies of both.

The finished generator frame is then ready for further assembly; armature, bearings, fan, main and commutating poles are installed without further application of welding. The masses involved are quite substantial, the commutator weighing around 5700 pounds, the generator field 6300 pounds, and the finished generator, ready for installation, some 12,950 pounds.

Proportionate Operating Advantages of Welded Freight Locomotive—With the contemporary demands for increased production, the need for the highest efficiency in passenger and freight transportation becomes ever more pertinent. Anticipating this need even before the present emergency, foundations were laid to consolidate previous experiences with a wholehearted endeavor to design a power unit exclusively for welding. This tendency resulted in greatly simplified welding practices, which ultimately led to an at least 50 per cent reduction in total time of delivery—a factor which certainly is paramount in the minds of production and defense officials. These benefits could naturally not be enjoyed without making specific analyses of all items hinging on the utilization of the welding processes. The metallurgical reasons were found to be definitely sound after practically not a single weld failure was recorded even with high-speed passenger locomotives. Thus it became a matter of selecting the most efficient welding machinery or generators to which appropriate welding electrodes and preferably down-hand technique must be added as decisive factors of economy. Most welding is, hence, done with 0.50 per cent molybdenum and some with straight low carbon steel electrodes ranging in diameter from 5/32- to 1/4-inch. Typical electrode data follows:

Diameter of electrode, in.	5/32	1/4
Length of electrode, in.	14	14
Normal current intensity, amp.	150	270
Voltage	27	35
Arc K.W.	4.05	9.45
Coating, per cent in 14 in.	18.9	21.9

Frequently, the current input is much greater, but actual settings depend on additional considerations, such as thickness of plate welded, degree and kind of necessary bevel, etc.

The generous use of manual and some automatic welding procedures

in the building of the first freight locomotives of the Diesel-electric class should probably be evaluated in the light of a new product. This is especially true because of the claims of older operating personnel of railroads, that the newcomer has replaced steam engines at the rate of one Diesel replacing two steam locomotives. While the present facts accumulated from actual operating record, are available, let us review the status of such important questions as tonnage hauled, average speed, daily mileage, fuel cost and similar items affecting the balance sheets of operations: Careful notes have been kept during the fact-finding runs over variegated terrain since 1940 and power was perhaps the first impressive advantage of the new units. Below are just a few of the experiences:

Railroad	Route Covered Between	Tonnages Hauled per Locomotive by		Percentual Increase Over Steam
		Steam	Diesel	
Boston & Maine	Mechanicville-E. Deerfield	4400	6500	48
	E. Deerfield-Boston	2350	5000	112
	Boston-E. Deerfield	2050	4000	95
	E. Deerfield-Mechanicville	2400	4200	75
Frisco Lines	Springfield-Tulsa	2550	4600	85
Monon Route	McDoel-Brainbridge	3075	5000	63
Erie	Marion-Kent	2800	5000	79
	Kent-Meadville	3100	5700	84
Southern	Oakdale-Danville	1750	3750	114

The next factor of interest is average speed. Although there never has been a bona fide attempt at any speed or tonnage records, even the first 5400-horsepower Diesel owned by the Santa Fé Railroad made the 1762-mile trip between Argentine, Kansas, and Los Angeles, Cal. at an average speed of 32.3 miles per hour. The locomotive pulled 68 cars or 3,150 tons. The locomotive had ample reserve capacity for moving a much heavier train and at much higher speeds. Generally, this run requires the services of seven steam locomotives with 12 stops for fuel and water besides 16 additional stops for water. The Diesel-electric freight locomotive stopped only four times to refill on fuel. Actual figures for several railroads follow:

Railroad	Route Between	Distance in Miles	Tonnage Hauled		Average Speed m.p.h.	Increase in Speed Over Steam
			Steam Loco.	Diesel Loco.		
Northern Pac.	Pascoe-Spokane	98		6000	26	160
Missouri Pac.	Kansas City-St. Louis	283	4800	5675	36	72
Kansas City Southern	Pittsburg-Dequeen	210	2650	3250	21	17
Milwaukee	Othello-Avery	212	4200	6010	26	86
Great Northern	Wenatchee-Minneapolis	1612		5400	31	Never Attempted
Baltimore & Ohio	Kelly Lake-Allouez	105		16200	26	44

Railroads are also interested in the maximum possible coverage of distances and greatest utilization of their expensive motive power. This gives some idea of both items:

Railroad	Average service hours per day (utilization)	Average daily mileage	Total mileage covered
Northern Pacific	18.3	376	5260
Missouri Pacific	20.0	435	4350
Chicago, Ind. & Louisville	20.2	271	1896
Chicago, Milwaukee	19.8	487	4872
Atchison, Topeka & Santa Fé	17.7	402	12871
Chicago, Burlington & Quincy	......	393	3929
Kansas City & Southern	......	373	3726

The foregoing tabulations are significant from an overall viewpoint of operations. When analyzing the details of the economies it will readily be noted, that they point distinctly to the use of liquid fuel, which may easily be handled and stored in welded tanks either at the terminal or en route with the locomotive. Fuel cost is therefore another index to feasible countrywide adoption of this new type of motive power in fast freight service. Fuel costs should be of interest in comparison with coal or oil burning steam engines:

Railroad	Mileage Covered	Cost Items	Steam Engine Coal Burning	Steam Engine Oil Burning	Diesel-Electric
Rio Grande	127	Cost of fuel	$2.36/ton		$0.045/gal.
		Consumption of fuel	336 lb.		2.84 gal.
		Cost per M.G.T.M.	0.397		0.124
Kansas City So.	430	Cost of fuel	$2.40/ton	$0.022/gal.	$0.045/gal.
		Consumption of fuel	150 lb.	7.5	2.15 gal.
		Cost per M.G.T.M.	0.1798	0.1642	0.0978
Santa Fe	81	Cost of fuel	$	$0.020/gal.	$0.0425/gal.
		Consumption of fuel		14.6	3.6 gal.
		Cost per M.G.T.M.		0.292	0.153
Missouri Pacific	283	Cost of fuel	$1.86/ton		$0.0375/gal.
		Consumption of fuel	58 lb.		1.03 gal.
		Cost per M.G.T.M.	0.0539		0.0384

In fairness to coal- and oil-fired locomotives, the application of Diesel-electrics in freight service should not be viewed from annual gross savings accruing from the above tabulated advantages alone. Maintenance costs, fair depreciation, expected availability and some additional items cannot be ascertained from the experiences acquired so far. There is no reason to believe that these entries on the balance sheets should not be maintained in the future years. Nevertheless, in scrutinizing the proportionate savings derived from the complete units, arc welding must be credited with the fact that it was this process together with the adoption of more modern genera-

tion and transmission of motive power, which resulted in these successes. The new locomotive is decidedly safer and easier to operate, is faster, does outperform any other steam locomotive, and is nearly 100 per cent available. These claims have been repeatedly substantiated by performance data in spite of most adverse traffic conditions. The true social advantages of the all welded Diesel-electrics will, without doubt, inaugurate a new era of their truly universal acceptance when materials shall again be available to private enterprise after serving our country to move more troops and their equipment at faster and more reliable schedules and at lowest operating costs.

Chapter II—Arc Welded Construction of "Fireless" Locomotive

By WALTER E. BARRON,

Foreman in Charge of Welding, Heisler Locomotive Works, Erie, Pennsylvania.

Walter E. Barron

Subject Matter: The application of arc welding to the construction of a "fireless" locomotive, or a locomotive in which the heat is stored in sensible form in a relatively large body of water under any convenient pressure between 100 and 500 pounds per square inch. Since running gear can be made much lighter and cheaper while still securing adequate strength, the size of the storage tank can be increased for the same overall weight of locomotive. There is no part of a steam locomotive, the writer states, that cannot be made in this way. Detailed descriptions of the manner in which all welded parts replace castings and forgings follow.

In 1933 the Heisler Locomotive Works of Erie, Pennsylvania, started to design and build a complete line of fireless steam locomotives from 20 to 100 tons, under the direction of Mr. Brian Wheeler as chief engineer. The writer had many years of experience with this type of locomotive with another company, which was considerable aid to Mr. Wheeler.

In 1940, when I wrote for information concerning the entering of the James F. Lincoln Arc Welding Foundation Program, the Heisler Locomotive Works was well established as builders of fireless steam locomotives.

Most of the cost data of the Heisler Works has been destroyed, therefore I will not be able to give as good a comparison of forgings, castings, bolting and riveting versus arc welding as I otherwise would.

Many people have never seen or heard of a fireless steam locomotive.

These engines take their source of energy from a stationary boiler and store the heat of the steam in the tank which is filled to 85 per cent with water. Any pressure from 100 pounds to 500 pounds is practical. The tank is insulated with 2½ inches of mineral wool.

When this engine was first designed the parts were either forgings, castings or plates riveted or bolted together. In the final design, they were built almost wholly by torched-out parts and arc welded together only where parts had to be made removable for repairs.

The writer was in charge of the welding for the Heisler Works. Many of the parts shown in the accompanying drawings were made without drawings, the drawings being made later.

In order to apply arc welding to its fullest extent, someone in charge of designing or constructing of the product has to be, what you might say, "welding conscious". One of the frequent errors is that the one in charge doesn't consider the fabrication of a welded structure, but tries to copy a casting or forging, putting in a lot of extra weight where it is not

Fig. 1. Storage tank.

Fig. 2. General arrangement.

needed on account of flaws that enter into castings due to shrinkage, cracks and sand holes.

I find many welders taking credit for the improved looks and quality of their product. In my opinion, 75 per cent of this credit should go to the builders of welding machines and rods.

Welding on a fireless steam locomotive is quite a big factor as you can make the running gear much lighter and cheaper than by castings and forgings, and still maintain adequate strength allowing you to increase the size of the tank, therefore more energy stored for the same over-all weight of the locomotive.

Fig. 3. False cylinder head covers.

The first 42-ton fireless steam locomotive built by the Heisler Locomotive Works, with castings and forgings bolted and riveted together, had a storage tank capacity of 435 cubic feet; the ones built by torching and welding had a tank capacity of 510 cubic feet, an increase of 75 cubic feet which was sufficient extra stored energy to work about one hour longer.

I don't believe there is one part on a steam locomotive that can't be fabricated by arc welding. Several years ago I made a model of a fabricated cylinder, also a model of fabricated wheels. Due to the low speed and low pressure, it did not seem practical for our purpose as they would have cost more than gray iron casting, but would have been much stronger. I believe someone has been issued a patent for fabricated cylinders with iron bushings to be used on high-speed, high-pressure road engines.

I made several sets of side and main rods which I don't have drawings for. So far as I know, this was never done before. They were constructed by using a high-grade steel casting for the ends, with bar steel

Fig. 4. Exhaust pipe.

for the body of the rod. This cut the over-all cost of these rods by about 60 per cent as it eliminated most of the machining cost. All they needed after welding was grinding and polishing with a hand rotary grinder and polishing machine.

The following shall be a description of the accompanying drawings being referred to by name and number. These prints don't show the welding as plainly as I would like so will need some explanation.

The storage tank, Fig. 1, was designed by Mr. Wheeler but made by one of the builders of unfired pressure vessels. The only openings in the vessel were the inlet and outlet steam passages, all the fastening of fixtures and mounting was done by welding pads to the shell, then tapping holes in the pads rather than using steam-tight studs which leave a potential leak. The fastening at "A" was formerly of cast iron chipped to the radius of tank with a special design of steam-tight tapered bolt which always was a source of trouble. The savings by welding was considerable, but the elimination of possible leaks was the main object. The internal steam pipe, marked "B", was formerly made of a gray iron casting machined with ball joints and studded in place. The savings on this job by welding was around $100, also eliminating any possible leaks. (Note the arch in this pipe to take care of expansion.)

The fastening, marked "C", was made by the use of ¾ x 3-inch bar steel set on edge making a box-section on top of saddle cross brace using 14¾-inch machine bolts to clamp it in place, letting the weld take all the thrust. This can be better seen by looking at drawing, Fig. 2, marked "A".

The internal charging pipe is patented and owned by the purchaser of

the Heisler fireless locomotive. I am not mentioning the purchasers' name as I have not asked their permission. None of the other parts are patented so they can be published if so desired. There is no way of making comparisons of cost with other methods used for injecting steam into water. This method is the result of many years of experimenting with all kinds of fancy nozzles and could only be accomplished by welding, as the vibration set up by injecting high-pressure steam into a large body of cool water is tremendous. This method is 100 per cent superior to any other method. The writer has seen 5,000 pounds of steam by weight charged into a tank in 11 minutes.

The false cylinder head covers, shown in Fig 3, were formerly made of cast aluminum. The figures are for a locomotive about half the size of the one shown on this drawing. The cast aluminum ones for the smaller size cost $84.34; the ones made by torching and welding cost $33.68, a base saving of $51.76. I don't have any figures for the larger size, but the savings would be proportionately larger. These savings were made on one set. If they were made in quantity, or if the parts were prepared on modern machinery, the savings would be greater.

The brake ruggin parts for a 4-wheel engine were formerly made by forging on the 4-wheeled engine; the time for forging was 32 man hours. The writer torched out and welded one set of them in 8 hours, a saving of around 60 per cent. Besides making these parts cheaper, they were much better as we had considerable trouble with forging breaking in the welds when they were forged.

Exhaust pipe, Fig. 4, could only be made by welding and there is no

Fig. 5. Rear bumper.

Fig. 6. Guide yoke cross brace.
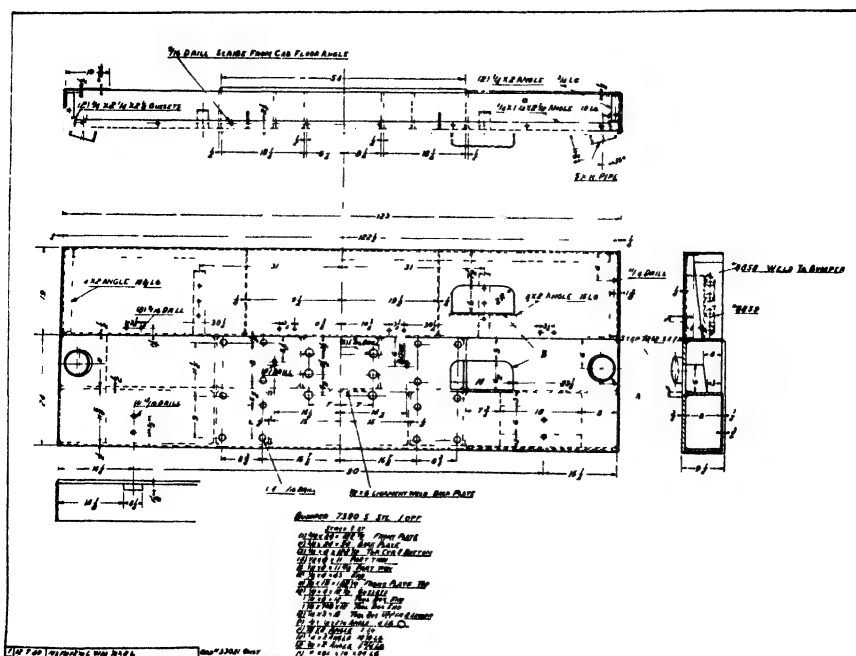
Fig. 7. Spring hanger.
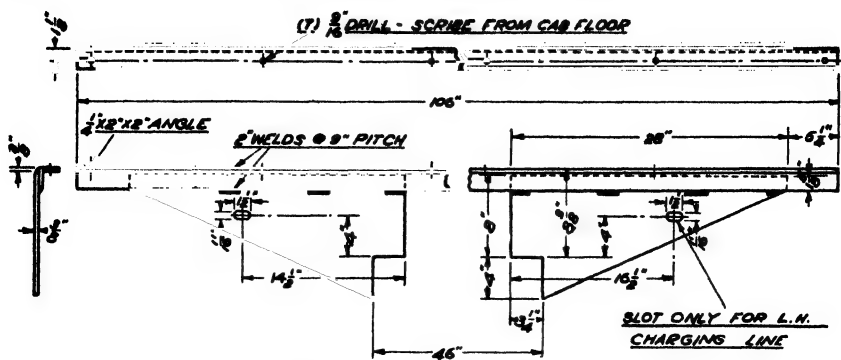
Fig. 8. Cab support brace.

comparison in cost. This pipe has to be very accurately made. This method was the first attempt to conceal this pipe under the false tank cover.

The rear bumper, shown on Drawing, Fig. 5, can be made of wood, cast steel or cast iron. I will only make comparisons with a wood bumper backed up and faced with ⅝-inch steel plates. A wood bumper of this kind has to be made of a good grade of seasoned oak lumber doweled and bolted together. For a smaller size than shown, the wood bumper cost us $125. The ones made by torching and welding cost us, in round figures, $65, not counting the parts such as push-pole pockets, marked at "A", and the steps marked at "B". If these were made of a casting, the saving by welding would be much greater. Most every locomotive of this kind takes a special bumper which makes welding still more advantageous. Still another reason for the welded type: many times you have to add weight at front or rear for balance. In this case, the compartments lend themselves very well to adding boiler punching and concrete. The strength is much greater than wood. In case of an accident, they will bend but are not likely to break. As for strength, they are equal to steel or iron, much stronger than wood and do not rot out like wood, having to be renewed every 4 or 5 years.

The guide yoke cross brace, shown on Drawing, Fig. 6, was formerly made of steel casting which was usually warped making it difficult to machine and was much heavier. Another reason for fabricating this part was delivery from the foundry. My memory is that the savings were around 40 per cent.

The axle bearing housing was not built until late 1940. This general style of housing was used from the first, all of one casting. From what I understand, it was poured standing on end, all the dirt floating to the top, many times costing as much to chip it out and weld as the original casting. The plates were 1045 material, heat treated, and gave us considerable trouble in welding at first due to the weld cracking. That was overcome by preheating before welding. The saving on this job was considerable.

The cab was formerly made by bolting and riveting. Heisler company made the first welded cab in 1936 for the Ford Motor Company. We got quotations from the outside for one similar. The cheapest price we got was $1,200, so Mr. Wheeler and I decided to give it a try. Material and labor, with overhead, cost us around $400, not counting the grief we had. There is not much diffierence in the cost between welding and riveting where every cab is different, the big advantage is when you go to paint
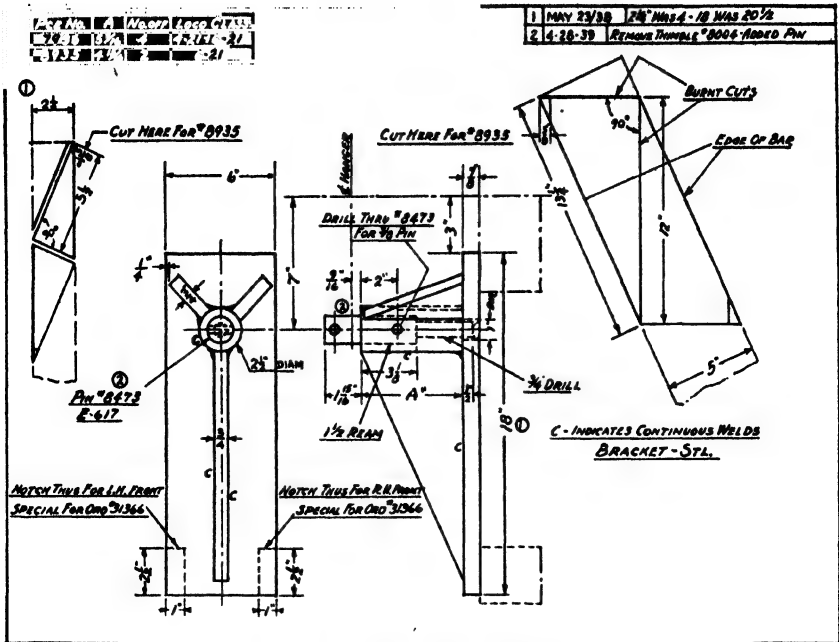
Fig. 9. Brake hanger brackets.
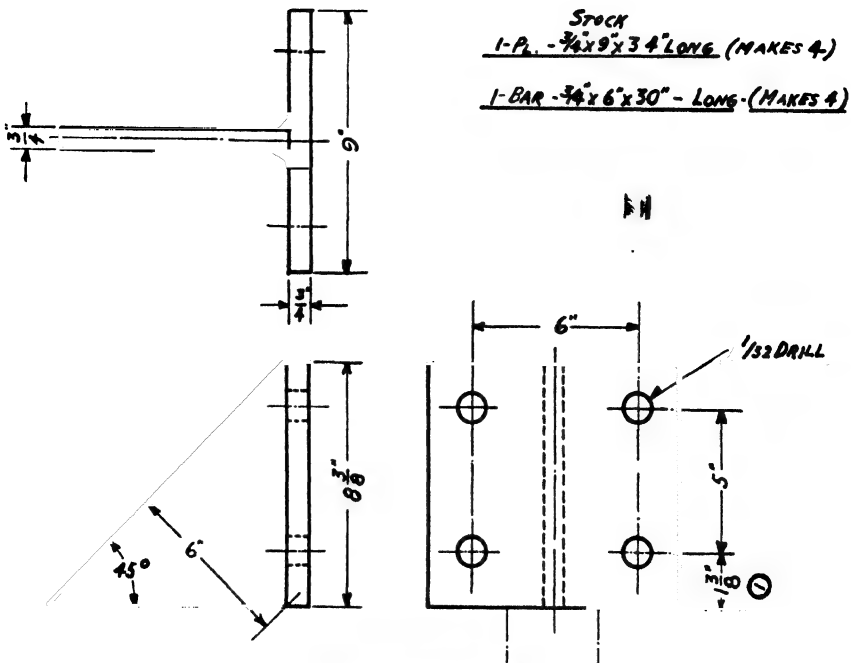
Fig. 10. Bumper knee.

and finish it. It is also a much more rigid job. In a shop having modern machinery and making several at a time, where templets and jigs could be used, the saving would be considerable over riveting and bolting.

The spring saddle was formerly made either by forging or casting, the forged ones costing considerable more than castings. The cast ones cost us $7.80 apiece, then had to be machined. The ones fabricated by electric welding cost $3.80 ready for use, a saving of $4, plus the cost of machining.

The steam elbow was formerly made of a gray iron casting and was subject to leaks from sand holes. It was a difficult piece to machine and prepare for the ball joint connection. The flanges on the fabricated ones were machined before welding. I don't have the cost on this part, but it cost less and was very much better on account of its flexibility.

The spring hanger, Fig. 7, was formerly made either by forging or casting, the forged ones being more expensive. The cast one cost $7.50 in the rough and had to be machined, the welded one cost $3.80 finished, a saving on each piece of $3.70. If they could have been made in quantity the saving would have been more.

The cab support brace, Drawing, Fig. 8, was formerly made of a casting weighing 450 pounds each, whereas the fabricated one weighed less than 100 pounds and could be welded in place, while the cast one had to be machined and bolted. I don't have the difference in cost but it was considerable. Also, if there had not been any cost saving, the difference in the weight would have warranted the fabricated one.

Brake hanger bracket, Drawing, Fig. 9, was formerly made by drilling a 2½-inch tapered hole in the frame, using a turned pivot, forging or casting bolted to the frame. Where the pivot fitted in the frame there was a tendency to weaken the frame, sometimes breaking through the hole. The same condition existed where bolts were used for this purpose. The rough casting cost us $7.80 then it had to be machined. The welded one cost us $3.50, making a saving of $4.30. This bracket also served to tie the upper and lower rails of the frame together, eliminating a very bad condition of chattering of the brake rigging when the brakes were applied.

The bumper knee, Drawing, Fig. 10, replaces a cast steel knee which had to be machined. I don't have any figures as to the saving but they were considerable, at least 50 per cent.

The saddle cross brace has several functions. In order for it to answer all its functions, it can only be a welded structure.

First, it acts as a spacer between the frame;

Second, it is the main support which keeps the frames in tram;

Third, the rear compartment is used to blow the excess water out of the tank that accumulates from condensation, guarding against scalding anyone who may accidentally be around. Before this safety measure was provided, several people were scalded;

Fourth, the front compartment acts as an exhaust box and separator as the exhaust steam from a fireless steam locomotive is very highly saturated. The baffle which directs the steam to the bottom of the box gives it a reverse motion which throws off part of the water letting it run forward on the tapered bottom to two small holes where it drains to the track.

Prior to the welded structure a steel casting was used which only partially answered these purposes. Every design takes a different cross brace and most every engine of the same design takes a different one, as most every engine took a different tank size and pressure which either required a new pattern or a change of pattern, this costing considerable money.
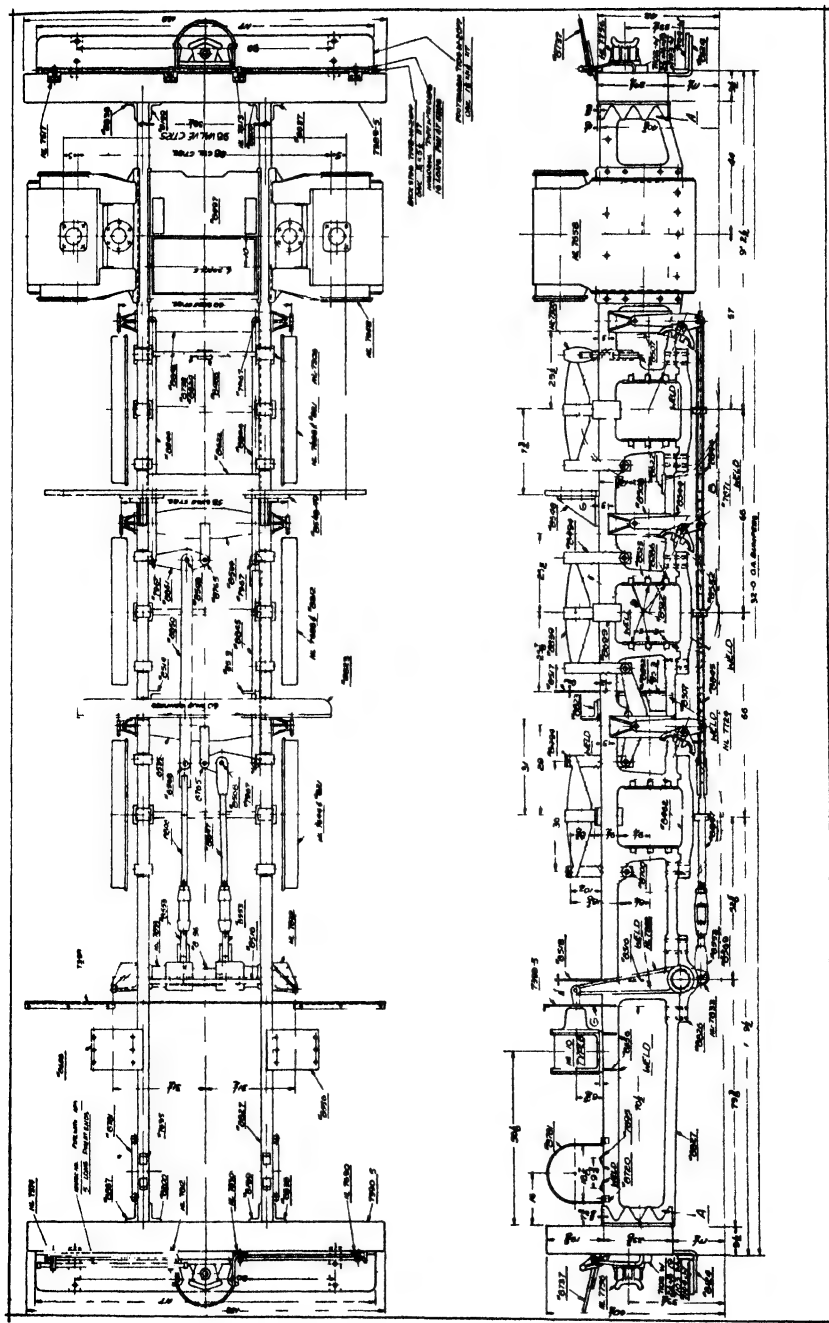
Fig. 11. Frame and brake rigging arrangement.
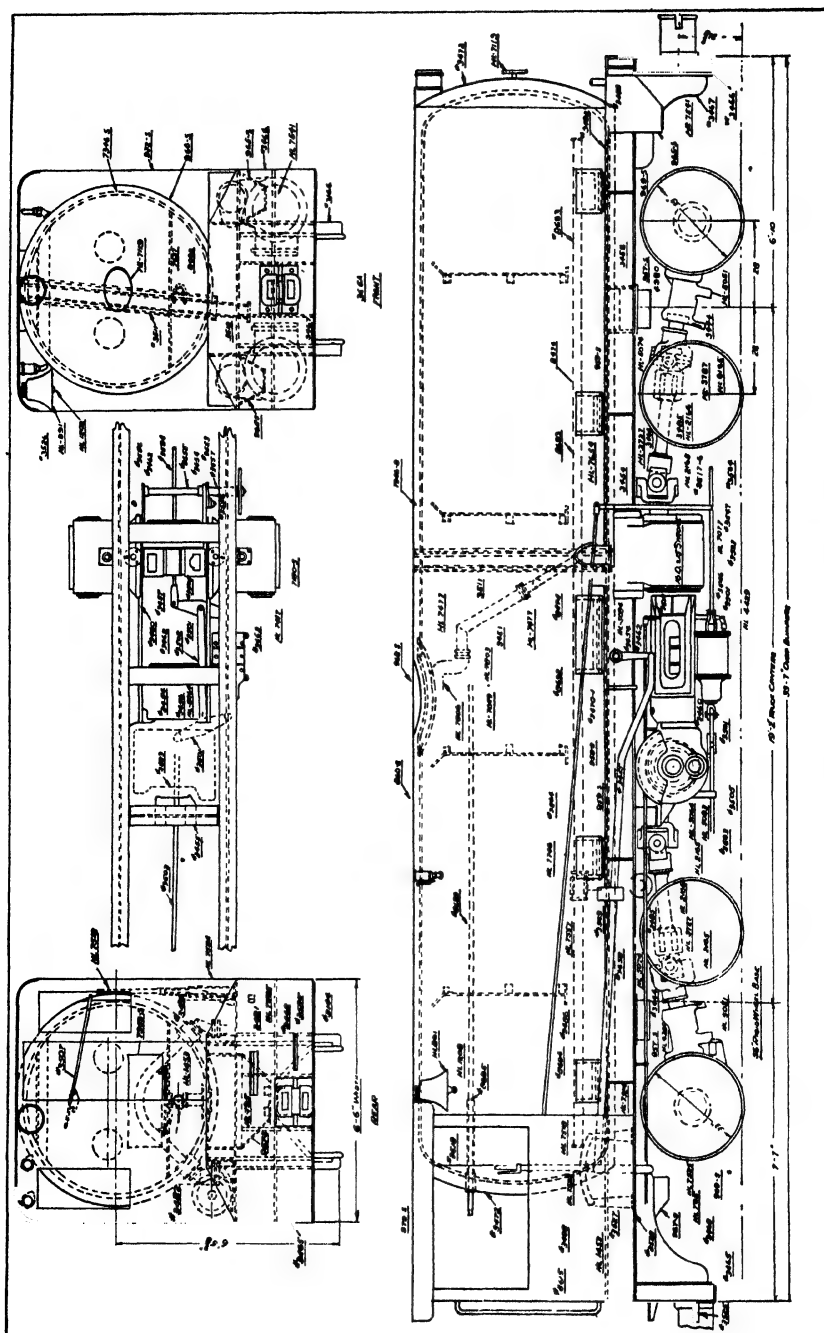
Fig. 12. Special design for 36-gauge track.

The rough casting cost us $147 and usually was warped on the finishing sides making it hard to set up and machine. The first welded one cost $96 ready for machining and was very much easier to machine on account of good clean metal. Still another advantage of the welded structure when it is finished and in place, is that it has to be welded all around where it fits to the frame so as to be steam tight. When the casting was used, considerable difficulty was encountered on account of porous places and sand.

Drawing, Fig. 11, shows the above described parts assembled in place by welding and many more that were not described. The whole locomotive is welded together. So far as I know, this is the most completely welded locomotive ever built,—note the "V" shapes cut out of one side of angles marked "A" to provide more welding. These are usually bolted on with 5 tapered reamed bolts.

A steam pipe casing was formerly an aluminum casting in 4 pieces. This casting was replaced with rolled sheets and clips welded together making a considerable reduction in cost. All pipe clamps and braces which are not shown are welded on. They were formerly bolted or studded welding a worthwhile saving besides giving a better job.

Drawing, Fig. 12, is a special design for one of the steel companies. This is for a 36-inch gauge track. Where this locomotive works the clearances are very close. The largest conventional locomotive this company could get into the charging side of their open hearth was a 30-ton. Their furnaces were being enlarged from time to time but no more room could be provided for the locomotives that served them until this engine was designed. This engine weighs 42 tons with a gear ratio of 3.57 to one giving it a tractive effort of at least that of a 50-ton engine. This engine could only have been built by welding. Every part of the main frame and tank were torched and electric welded. The bumpers are made as part of the main frame which is unusual as they are usually made removable. Another unusual thing about this locomotive is that the engine unit is suspended between the two four-wheeled trucks and can easily be removed for repairs. The exhaust pipe goes up through the center of pressure tank. Conventional locomotives are always anchored at the front, all expansion being toward the rear. In this case, the tank is anchored in the center and expands both ways. This locomotive was designed by Mr. Brian Wheeler, chief engineer and manager of the Heisler Locomotive Works. It is a combination of a Heisler geared locomotive and the fireless principle.

It would be impossible to make any cost comparison as there has never been anything similar built but it does help to show what can be done in the line of torching and electric welding.

If this paper and drawings encourage someone to try some new product by torching and welding, I will consider my time in preparing it well spent.

There have been some marvelous things accomplished by torching and welding but we have only scratched the surface as to what can and will be done in the future.

All savings given are with labor, material and overhead figured in.

Chapter III—Welding a Locomotive Boiler

By JOHN P. ROGER,
Plant Engineer, The Babcock and Wilcox Co., Barberton, Ohio.

John P. Roger

Subject Matter: A number of welding applications to parts of a locomotive boiler, intended to constitute the steam generating unit in a complete, mobile power plant including condenser, steam turbine, generator, etc. For example, it is proposed to roll a special form of steel channel, press to rectangular shape and weld, in order to make the tube headers. Other items, similarly analyzed, include the main steam outlet connection to the steam drum, with wall element, superheater assembly, condensing water storage, etc.

The welding developments herewith described and illustrated had their origin in a previous study and design which I had developed for a locomotive, the main features of which were that it would be a complete steam electric motive power unit, in that it was self-contained; the principal components of which would be a boiler of the water tube type; the steam generated therein would have a pressure somewhere between 500 pounds and 1000 pounds, and contain a steam superheater which would elevate the temperature some 200 to 250°F. above that of the saturated steam. This steam would be conveyed to a steam turbine of the compound type, directly connected to an electric generator, and exhausting its steam into a condenser of the evaporative type. The electric power would then be conveyed to motors mounted on the locomotive trucks and in this manner develop the propulsive power for the unit.

I have prepared sketches illustrating my primary idea of such an assembly, which will be known as Figs. 1 and 2.

When I received the prospectus of this competition regarding welding developments, I selected the above-described locomotive as the basis of my efforts along this line, and the following descriptions and illustrations will show my progression up to now, in developing welded constructions to replace the present method of fabricating these same structures. My idea now is, to produce a locomotive design of completely welded construction, fully streamlined, and self-contained, the power generating unit of which would compare in operating cost and efficiency with the most modern fixed units generating this type of power. My efforts in these welding developments, while expended primarily in connection with this locomotive design, will apply to many different units outside the locomotive field, and as water tube boilers are my everyday job, I have selected most of the developments from this field. There are many types of water tube boilers, but the ones I have selected for this competition are two which I find best adaptable for this description, and are composed of drums, headers, and all of their connecting tubes and fittings. The only material difference in them is the method of
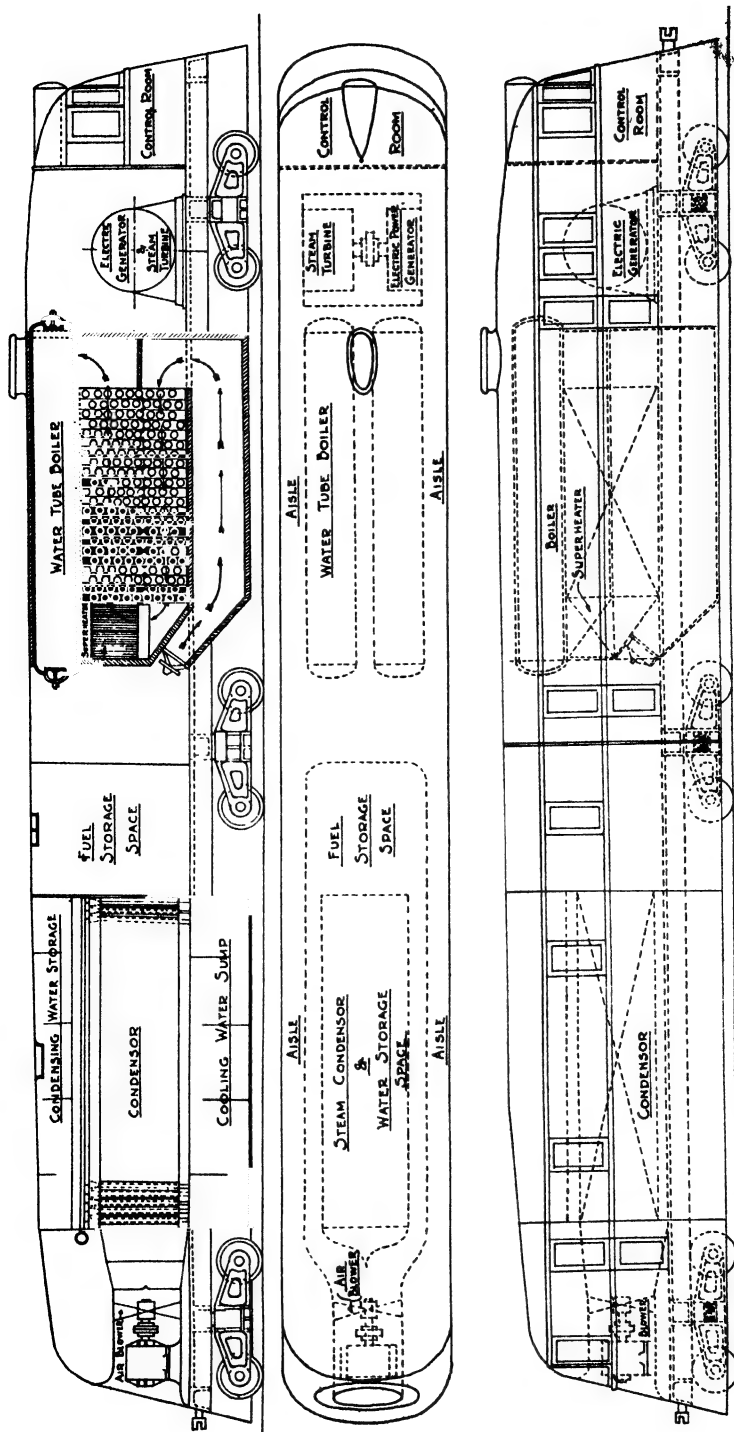
Fig. 1. Primary general arrangement of steam electric locomotive power unit. Sectional view (top), top plate (center), side elevation (bottom).
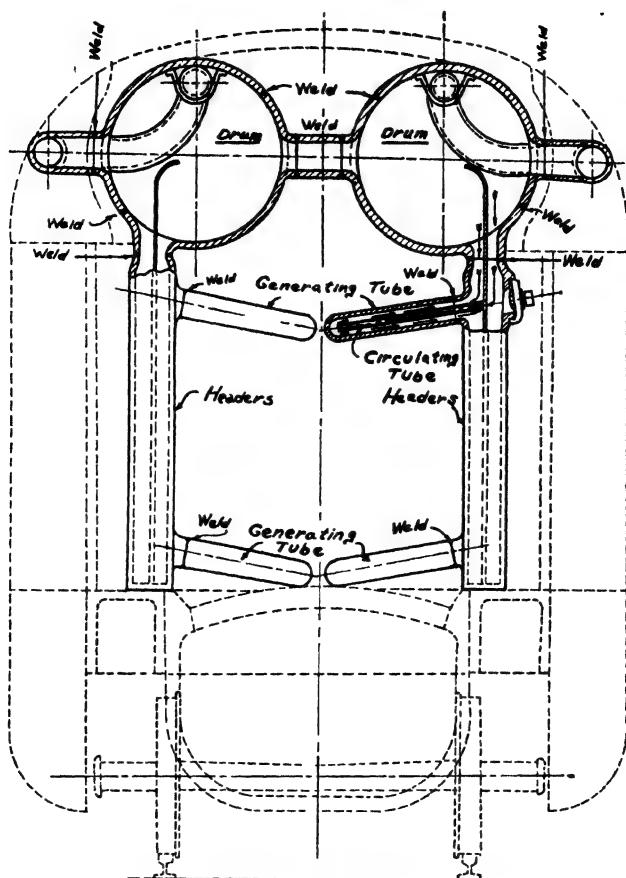
Fig. 2. Vertical cross section of boiler.

arrangement of these different components to do the job that they were designed for.

Under the present fabricating setup of these components, the drums are mostly of welded construction. Both the longitudinal and girth seams are welded as are also the opening fittings that form part of the completed unit.

The headers, under present-day methods of fabrication, are made mostly from hot-rolled seamless tubes and then by a series of forging and machining operations are transformed into rectangular boxes with openings on one side to receive the tubes, and on the opposite side a handhole cover plate, together with an arch bar and stud to make a steam-tight joint between the header and the plate with the use of a gasket between the faces of the headers and the cover plates.

The tubes are the next essential unit, and they are fastened into the headers by means of a roller expander with a tapered pin which rolls the tubes out against the hole in the header and by this means makes a steam-tight joint when the pressure is developed in the boiler. This, in the main,
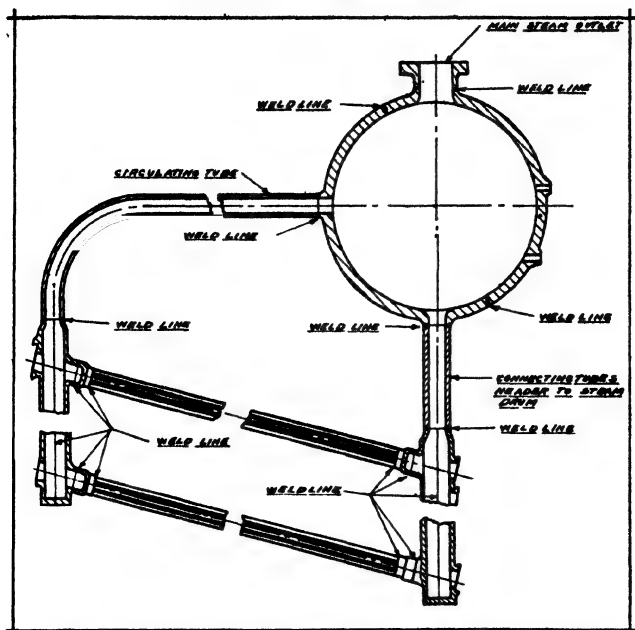
Fig. 3. General assembly of headers, tubes and steam drum.
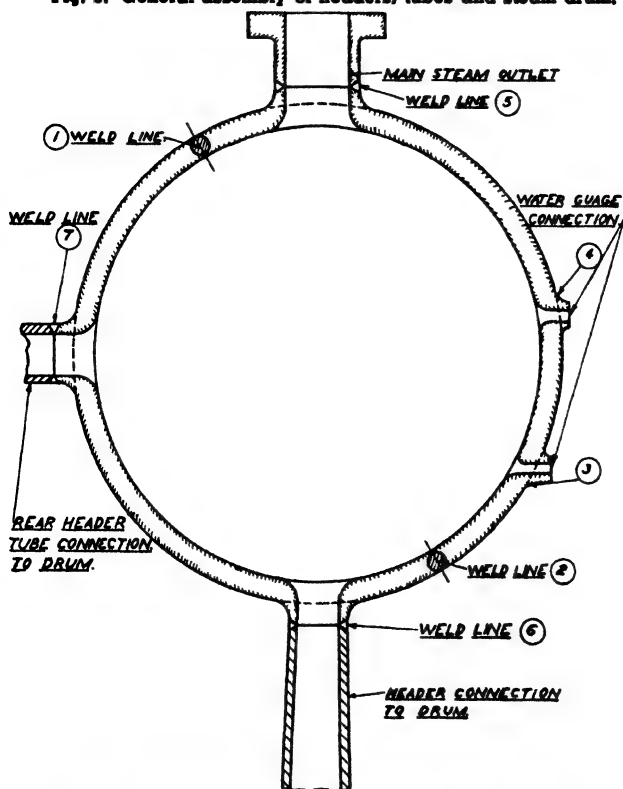
Fig. 4. Enlarged cross section of main steam drum.
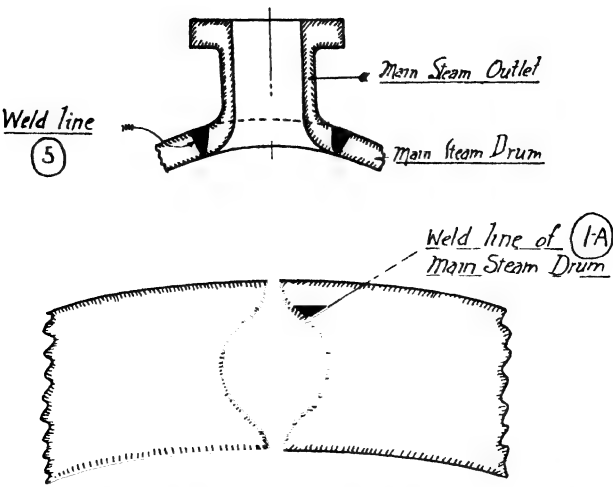
Fig. 5. Enlarged section of main steam drum through weld.
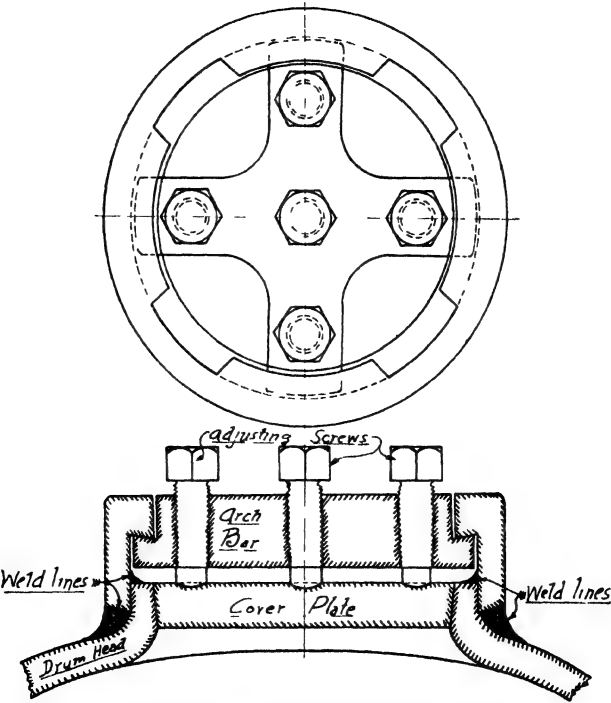
Fig. 6. Cross section of man-hole opening in drum head.
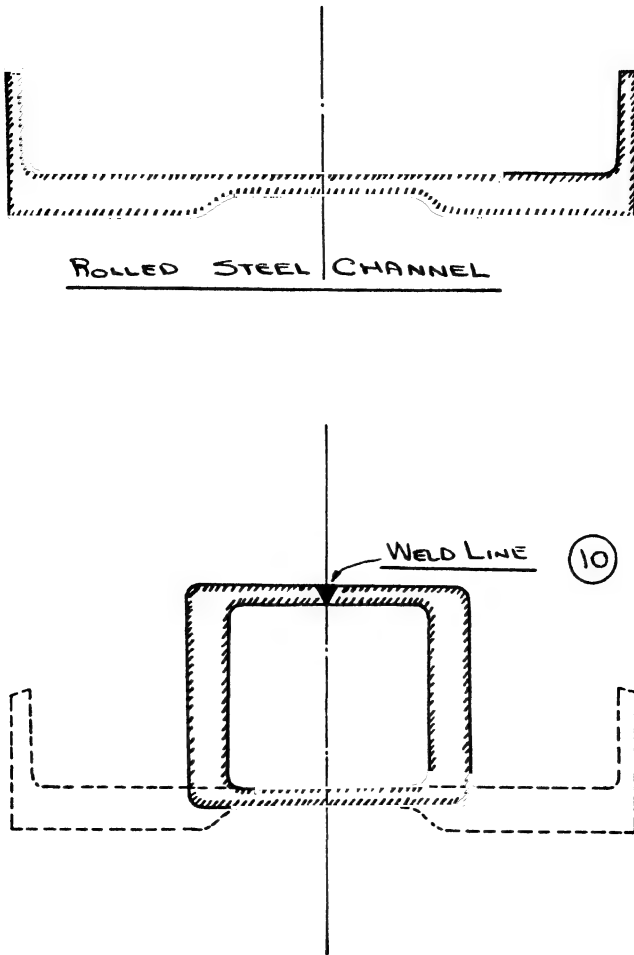
Fig. 7. First forming operation.

constitutes the present setup of the boiler unit, and to make more clear the welding developments, I have in mind to replace the setup described above, I have prepared Figs. 2 and 3, which illustrate with cross-sectional elevations the points where I propose to substitute arc welding for the present methods of making these steam-tight joints.

Fig. 2 illustrates the type I have selected for the steam electric locomotive service, and Fig. 3 illustrates a type mostly used for land and marine service.

The components of the two different types are similar, the difference being in their arrangement in the final assembly.

Fig. 4 illustrates an enlarged section of the steam drums and shows more clearly in detail how I propose to connect the different components to it. Illustrated on this sketch are seven welded joints: 1 and 2 are the longitudinal welded seams which are arc welded by the standard method for this class of work.

On Fig. 5, I show an enlarged view of the joints marked Nos. 1 and 2.
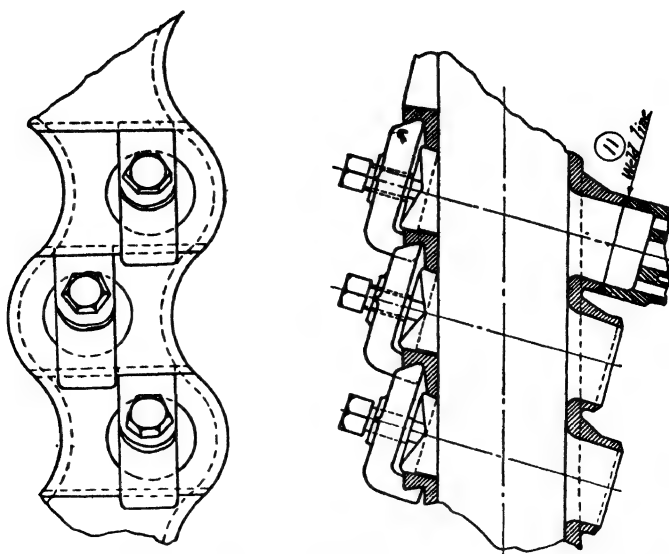
Fig. 8. Vertical section and side elevation of a staggered header.
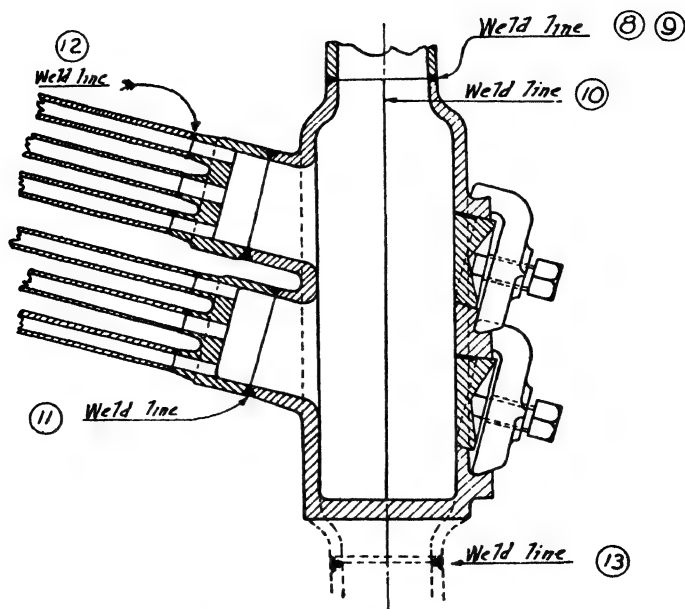
Fig. 9. Vertical section of staggered header.
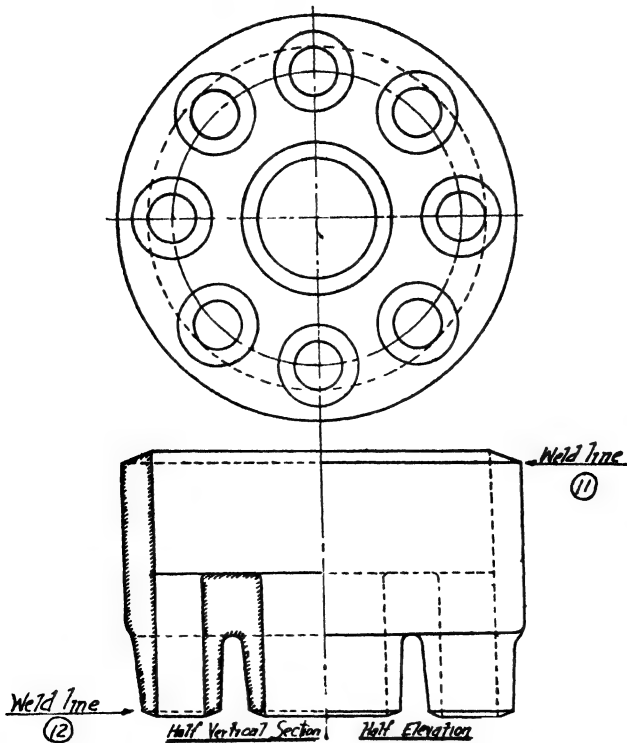
Fig. 10. Collector element for steam generating tubes.

which I have developed to replace the above-described standard method, which has, as its main object, an increase in the efficiency of production of this type of component. Welded joints Nos. 3, 4, 5, 6 and 7 are obtained by flanging the drum plate at these points, following the forming of the flat plate into its final circular form, the openings being sized to correspond with the attaching connections.

Fig. 5 also illustrates an alternative method of making the main steam outlet connection No. 5 to the steam drum, though it will involve a little more expensive outlet fitting.

Fig. 6 illustrates a manhole opening cover plate assembly for the steam drum which I believe is much simpler than the type in general use for this service and is fabricated by flanging the drum head out at this point, and by welding on the outer face of this flanged portion a keeper ring which is slotted at four points, so that the arch bar can be inserted and removed when opening and closing the cover. The cover plate, itself, is held in place by five adjusting screws, mounted in the arch bar, and the joint between the drum head and cover being of the tapered metal-to-metal type and free of gaskets, is capable of adjustment at all times by the afore-mentioned screws. The maintenance factor of such a joint is very low and the safety factor high. The fabrication cost of this type of manhole cover with the present type would be somewhat less and the maintenance cost would be considerably less.
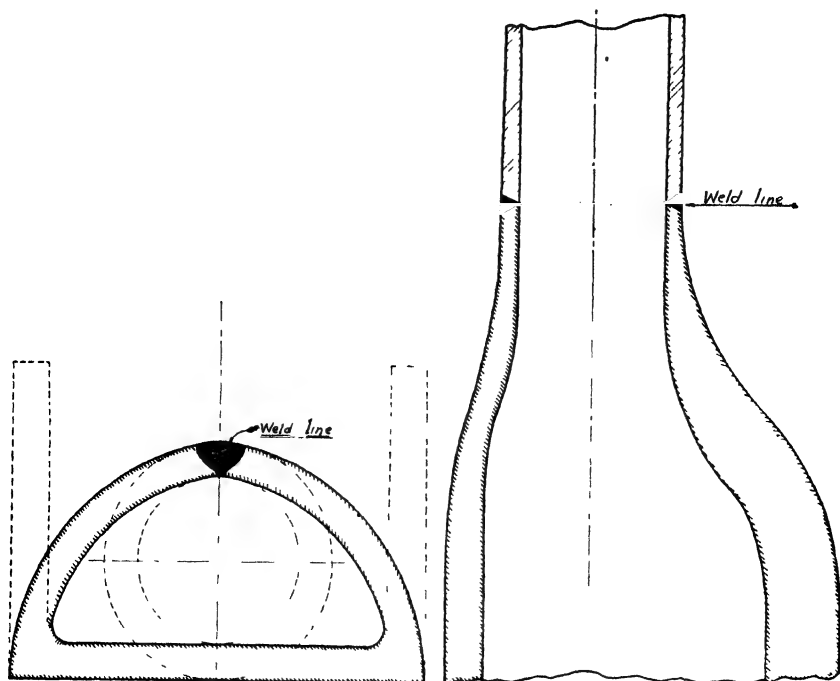
Fig. 11, (left). Cross section of water wall element. Fig. 12, (right). Enlarged section of water wall element showing welded end connections.

Figs. 7, 8 and 9 illustrate the steam generating tube headers or collectors, and show the welding developments that I propose to substitute for the present fabricating methods, as described in a previous paragraph. Fig. 7 shows, in the upper view, a rolled steel channel which it will be noted has two different thicknesses of the web, so that when formed into a rectangular box, as shown at the bottom of the sketch, will have two opposite sides thick, and the other two thin. The weld line of the box will then come at point 10, and from an economical standpoint, it might be advisable to have these channels rolled in lengths which are multiples of the required header lengths, and following the forming and welding operations they can be cut into the desired lengths for staggered headers.

Fig. 8 illustrates a vertical section and side elevation of the completely fabricated header. It shows, in the sectional view, how the rectangular box, described above, is further operated upon to give the results shown in this view. The rear or tube side of the header is flanged out to provide a proper welding face, as shown at point 11, for connecting the end of the generating tubes of the boiler to it. The front face of the header is arranged to contain a handhole cover plate opposite its aligned tube and is held in place by the stud bolt threaded through the arch bar, which, in turn, takes this thrust in grooves provided on this face of the header for this purpose.

Fig. 9 is a vertical section of the header, together with the connecting tubes. It also illustrates how the top and bottom ends of the header are
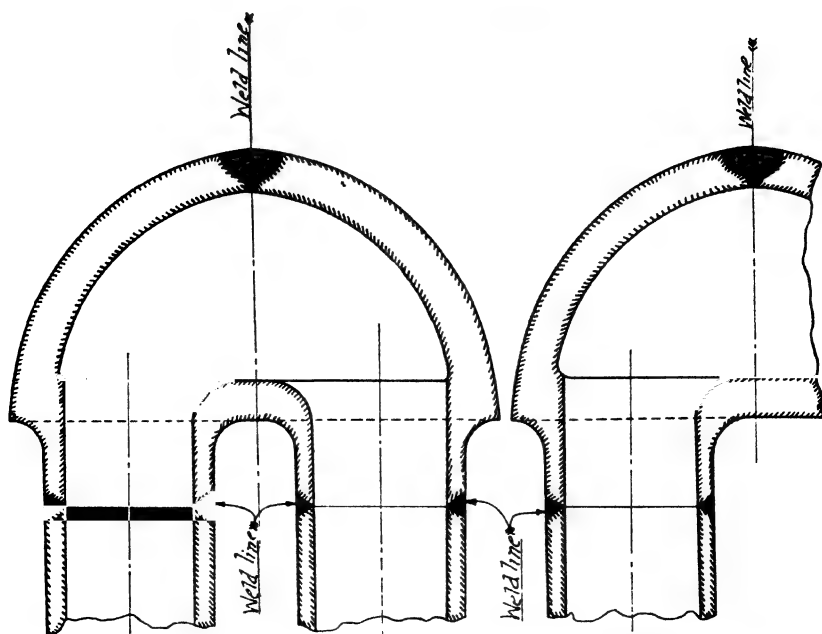
Fig. 13. Cross section of water wall element arranged as a superheater assembly.
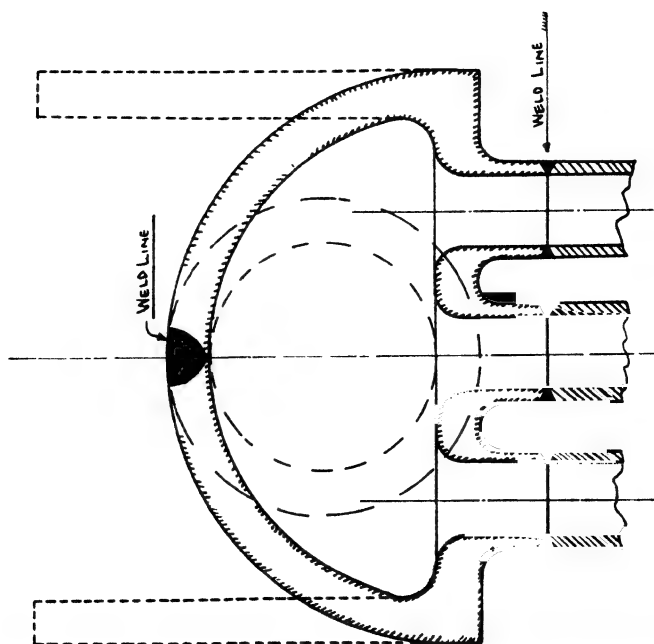
Fig. 14. Cross section of water wall element adapted to superheater header construction.
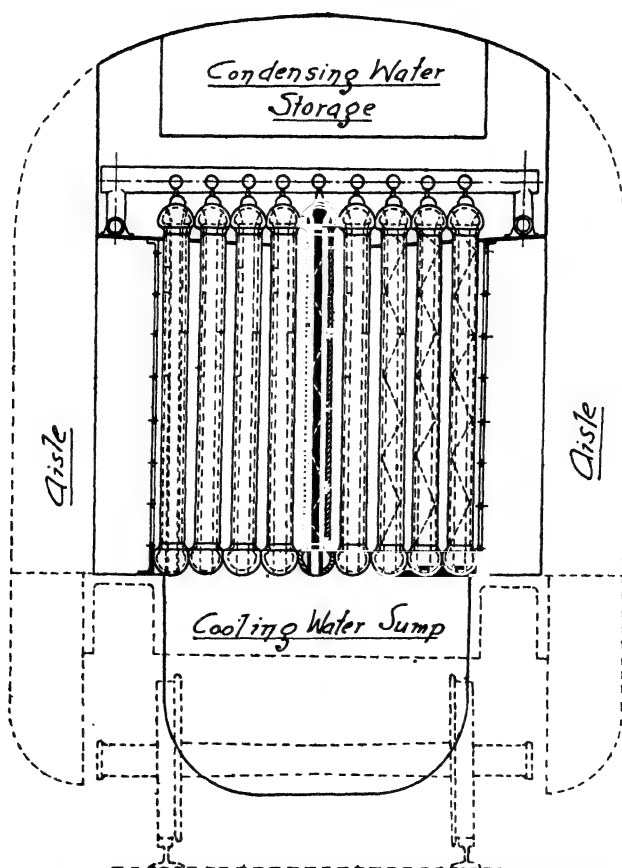
Fig. 15. Sectional elevation of condenser for locomotive service.

processed to give on the top end a connection to the steam drum, and on the bottom end either an opening similar to the top, or a blank end, whichever is desired. The method of making these and all the other welded connections in these headers at 8, 9, 11 and 13, are for clearer visualization illustrated in Fig. 3. The connection of the tube collector element to the headers is clearly shown at welding point 11, and the welding of the steam generating tubes at welding point 12.

Fig. 10 shows an enlarged view of the collector element for the steam-generating tubes, with the arrangement of the generating tubes within the element, and the welding points eleven and twelve to the header and tube respectively.

Figs. 11 and 12 illustrate a component that most large steam-generating units of today are equipped with. They are termed water walls, and take many different forms by different vendors, the most common being a plain tube with various heat-absorbing mountings to take the place of the fire brick walls, of which the furnace chamber is built.

Fig. 11 illustrates an element for this type of service, which I have developed for this service, and which has as its basic form a rolled structural
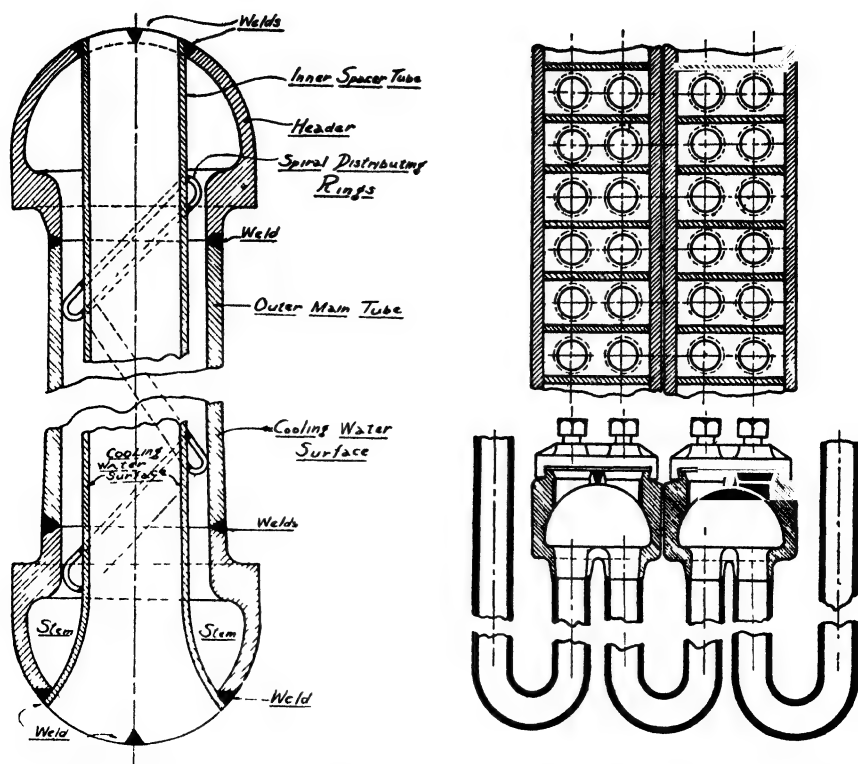
Fig. 16, (left). Enlarged view of condenser tube unit. Fig. 17, (right). Assembly of economizer unit.

channel, which by a series of fabricating operations is changed to the form shown on this sketch, with the two adjacent ends of the formed box welded at the point shown, making an ideal element for this type of service, and presents to the furnace side a solid water-cooled straight face. The fabrication cost of this unit, in comparison with others on the market, is very much in its favor, and the method of connecting these units to the main header or collector is simplified by closing the ends down to the form shown on Fig. 12, and then welding them to the flanged openings in the main header.

Figs. 13 and 14 illustrate applications of the element shown on Fig. 11 to the service of steam super-heaters, either with double- or triple-flanged welding ends for connecting to the main generating tubes of these units. This, in turn, makes a very simple and compact unit for this service, the size being limited only by the lengths possible to be obtained from the rolling mills of the main unit. The fabricating cost of this setup, in comparison with other types for this class of service, is in favor of this type of construction.

Figs. 15 and 16 illustrate a sectional elevation of the all welded condenser I have developed for this locomotive, the main headers of which are made up from the same section shown on Fig. 11, which adapts itself very nicely to this class of service.

Fig. 16 illustrates an enlarged view of the main condenser units, showing the headers and the inner and outer tubes assembled in place. The main
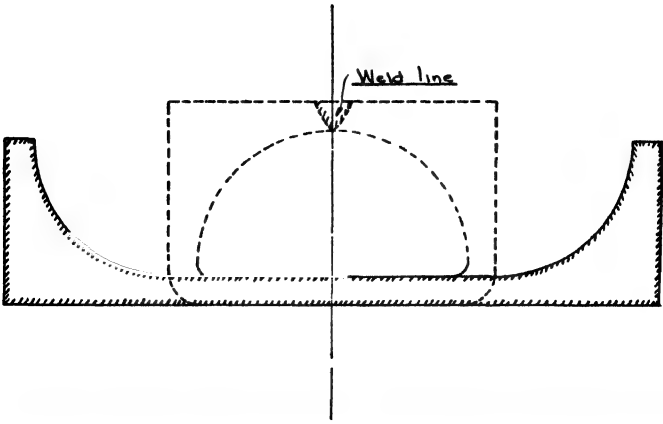
Fig. 18. Rolled channel blank for forming economizer and superheater headers.
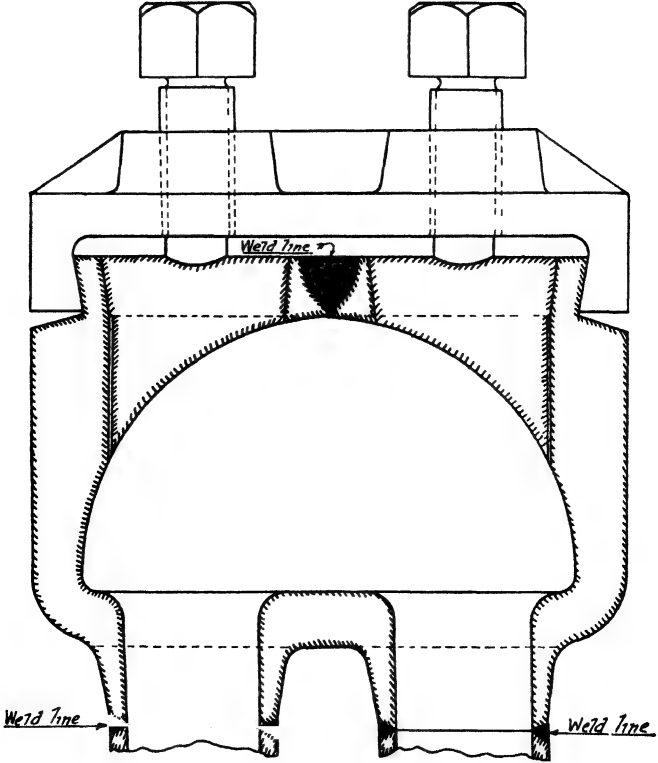
Fig. 19. Cross section of economizer header section.

idea in this setup is to break up the film of cooling water into the thinnest possible, thereby increasing its efficiency for condensing purposes. The fabricating cost of this setup, in comparison with other types, should be very much in its favor.

Figs. 17, 18 and 19 illustrate an arrangement of an all welded economizer section which is used in a steam-generating plant to raise the temperature of the feed water by using the waste or stack gases for this purpose.

Fig. 17 illustrates a two-header arrangement, complete with tubes, handhole covers, and arch bars. The basic form of the main header is a rolled channel structure illustrated on Fig. 18 and following the first refabricating operation will appear as shown by the dotted lines on this sketch, with the weld line coming as shown at the top of the rectangular box. Fig. 19 illustrates an enlarged sectional elevation through the header and its fittings, showing the bottom face flanged to form the tube welding connections, the upper face being machine-bored to take a tapered handhole cover plate, which is held in place by a stud threaded through the arch bar, which takes this thrust from under cut grooves in the top side of the header. This makes a simple, economical and efficient setup for this type of unit, and maintenance costs will be very low.

I might say in closing this paper that the boiler here described for locomotive service for this type of an installation would also adapt itself for replacement service on present-day locomotives and thereby increase their efficiency, and decrease their operation cost, and the field, for this class of business, would be very large. Time will not permit me to illustrate the many possibilities I have in mind for the other components in this locomotive design, so this must be left to some future effort

Chapter IV—Welded Design of 250-Ton Flat Car

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Subject Matter: Problems of riveting a 250-ton flat car appeared almost insurmountable. The only other alternative to a welded body was a steel casting involving the cost and delay attending the use of an expensive pattern. Since no precedent existed for the construction of a car of this capacity, careful design analyses were made. They are presented in considerable detail and include both stress and deflection investigations. Problems of shop fabrication are discussed in the light of the necessity for guarding against distortion and impossibility of stress relieving the entire structure. In the cost summary, a saving of 2 cents per pound or about 14 per cent in favor of welding is indicated.

An unusual structure presents the designing engineer with new and unusual problems, as well as with unusual opportunities. The 250-ton flat car to be described in this paper was unique in size and weight and also in the fact that the main body of the car was completely welded. A belief that a concise account of the design of this welded structure would contribute to the preparation and to the economy of time in the preparation of other similar or related designs in the future has prompted the selection of this particular subject for discussion.

The tremendous demands for steel brought about by the war created an urgent need for a car that could transport ingot molds weighing 250 tons and other heavy products. Time was the vital and compelling factor in the prompt construction of such a car, in the face of which it was necessary to use available material, as far as possible, and to maintain a simplicity, even at the sacrifice of some additional weight.

No precedents existed for a car of so great a capacity and the basic specifications were simple and brief. They were as follows:

1. Loading platform to be 18 feet long and 9 feet 8 inches wide.
2. Height of platform (when loaded) to be 2 feet 6 inches above top of rail.
3. Load to be 500,000 pounds distributed uniformly over the platform.
4. Car to meet all interchange regulations of the Association of American Railroads.

Having been designed in accordance with the last item, the car can be shipped over any railroad, provided that railroad meets the A.A.R. clearance diagram and its bridges have the necessary strength.

Two feasible methods of construction presented themselves—either fabricated rolled steel or of unit cast steel. It was realized that welding of rolled steel offered a simple and ready means of producing a unit structure. On the other hand, cast steel construction, while offering a ready means for constructing the curved sections of the platform beams, involved, among other large scale operations, the making of an expensive pattern and the probable lengthening of the time to completion of the car. Welded fabrication was chosen for

its potential advantages which subsequent design studies resolved to a series of relatively simple and economical construction procedures, thereby justifying the choice between the two methods.

The total rail load of the car was estimated to be somewhat in excess of 800,000 pounds, a weight which necessitated the use of twelve axles with 7-inch x 14-inch journals, each axle having a rated capacity of 70,000 pounds.

The general arrangement of the car, as finally developed from the basic specifications, is shown in Fig. 1. The main body is of the depressed center type and is supported at each end on a car structure mounted on two six-wheel trucks. Welding was used throughout the main body and to some extent
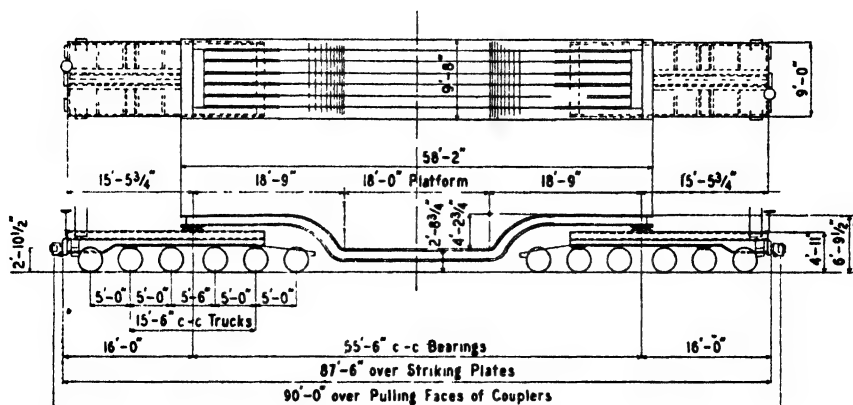
Fig. 1. General arrangement.

in the end supporting structures. The final design was not achieved without a very considerable amount of preliminary calculations to establish dimensions and weights. In presenting the design computations for the main body of the car, only those will be used that refer to the finished structure.

Fig. 2 shows the cross-section at the center of the car, from which it will be seen that the main body was made up of seven longitudinal beams placed side by side and welded together at their top and bottom flanges. The A.A.R. Unrestricted Clearance Diagram was of controlling importance because all of the car structure had to come within the limits of the diagram. It was a fortunate circumstance that the final selection of beams gave the specified width without any trimming of the top flanges. Owing to the inward taper of the lower portion of the diagram it was necessary, however, to cut off the bottom flanges of the outside beams—the effect of which will be discussed under the topic of design.

The dimensions of the beam sections are given in Fig. 3. It was evident that there was no practical way to bend beams of such size and length into the curved shape of the main car body. Moreover, there were distinct advantages in dividing each longitudinal beam into five parts—the straight platform section, the two curved transition sections and the two straight end sections—then welding all five sections into a single beam. For the curved portions it was decided to build up the sections from plates as shown in the lower left-hand sketch of Fig. 3. One incidental gain from this subdivision of the beams into five sections was the possibility of using lighter beams for the end portions to effect some considerable weight saving.
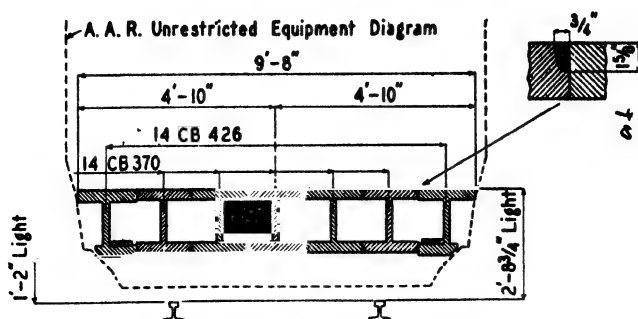
Fig. 2. Cross section at center of car.

With this general arrangement decided upon, the design calculations were carried out. These calculations will be concisely set forth in the immediately following portions of this paper and then followed by a description of the welding operations.

Before the final design could proceed it was necessary to settle upon the working unit stresses for the steel. Preliminary calculations had shown that it was impossible to pack sufficient beams within the limits of the clearance diagram when a working stress of 16,000 pounds per square inch was used. This clearly called for the use of a higher working stress and the use of a high-tensile steel. Another compelling reason for the use of a high-tensile steel was that of keeping the weight of the completed car within the capacity of the twelve axles.

In such heavy rolled sections it is impossible, without increasing the amount of carbon and other alloying elements, to secure the same strength properties that are normally obtained in material of lighter and more usual thicknesses. Since these beams were to be spliced and joined together by welding it was decided to limit the carbon to 0.20 maximum and accept a lower yield point. Ordinarily, the selected analysis of nickel-copper structural steel would give a yield point of 50,000 pounds per square inch but in these thick beam sections, the mills would not guarantee a minimum of more than 40,000 pounds per square inch. The actual values of the yield point of the material, as rolled, ran between 42,000 and 44,000 pounds per square inch.

For the combination of dead and live loads it was decided to use a factor of safety of 1.875 and when the end buffing load was added to the combination of dead and live loads, the factor of 1.75 was deemed adequate. On the basis of the guaranteed minimum yield point of 40,000 pounds per square inch the unit working stresses were as follows:

Loading	Unit Stress
Dead + Live	$\frac{40000}{1.875} = 21330$ say 21500 p.s.i.
Dead + Live + Buffing	$\frac{40000}{1.75} = 22860$ say 23000 p.s.i.

The loading diagrams for the main car body are shown in Fig. 4. The upper sketch outlines the structure and gives the principal span dimensions. The splices were located at points A and B. The dead load figures are based upon the estimated weight of the final design and the live load is in accord with the third item of the basic specifications. The buffing load is the standard A.A.R. requirement of 250,000 pounds, which was assumed to act at the underside of the end beams where the center plate applies the load to the main car body.

The first step in the design was to select the sizes of the beams at the center of the car where the maximum stresses occur and the calculations required for that determination will illustrate the procedure.

Moments at Center of Car

Dead Load M = (71385 × 27.75) — (19640 × 22.44) — (30680 × 12.56) — (21065 × 4.0) = 1,070,600 ft.-lbs.

Live Load M = 250,000 (27.75 — 4.50) = 5,812,500 ft. = lbs.
Buffing M = 250,000 × 3.67 = 916,700 ft.-lbs.

	Car Body	Per Beam (7 beams)
Dead + Live	M = 6,883,100 ft.-lbs.	983,300 ft.-lbs.
Dead + Live + Buffing	M = 7,799,800 " "	1,114,260 " "

Complete moment diagrams are given in Fig. 5 and convey a good idea of the manner in which these moments vary.

As a preliminary size, a calculation can be made of the required section modulus for one beam, on the assumption that each beam carries 1/7 of the total load, which is an equal distribution of the load among the beams.

Dead + Live Required $S = \frac{983{,}300 \times 12}{21{,}500} = 548.8$

Dead + Live + Buffing Required $S = \frac{1{,}114{,}260 \times 12}{22{,}670} = 589.8$

The greater section modulus, 589.8, requires a 14CB370 for which S = 608.1. The unit stress of 22,670 may need a word of explanation. The end compression of 250,000 pounds, or 35,710 pounds per beam, produces a stress of $\frac{35{,}710}{108.78} = 330$ pounds per square inch in a 14CB370 beam and this was substracted from the allowable working unit stress of 23,000 pounds per square inch, in order to get the net stress that remained for the bending.

The assumption was made that the load was distributed equally among the beams and this is the ideal distribution. This assumption will hold only if certain conditions are fulfilled. It is evident that crosswise of the car the platform will remain level under the load and also because the beams are joined together by welding. In other words, the deflection of all seven beams will be the same. It can be readily shown that for equal deflection, the total load will be divided among the beams in proportion to their moments of inertia. This has a direct bearing upon what has to be done when we remove
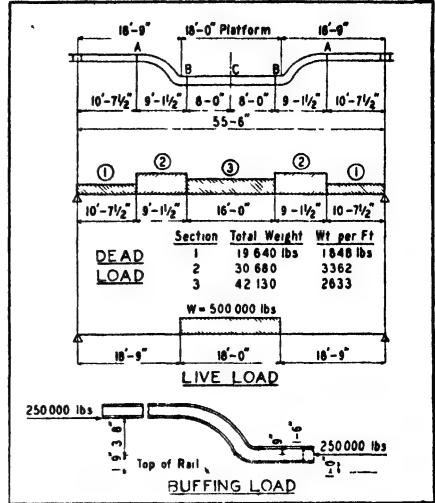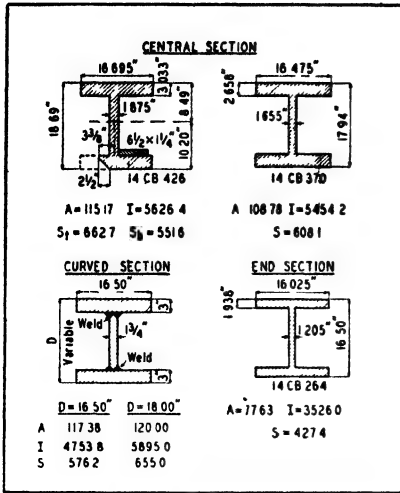
Fig. 3, (left). Beam sections. Fig. 4, (right). Loading diagrams.

the bottom flanges on the outside beams to keep with the clearance diagram.

The final section of the outside beams was determined only after a number of trial sections were investigated and probably, if more time had been available, a slightly closer balance of top and bottom flange stresses might have been achieved, although the result was considered satisfactory. It will be noted that a 14CB426 beam was utilized with a reinforcing bar added on the inside bottom flange to balance the flange material that had to be removed. The section and its properties are shown in the upper left-hand sketch of Fig. 3. The moment of inertia of 5626.4 is in reasonably close agreement with that of 5454.2 for the five interior 14CB370 beams, hence with equal deflections, all seven beams will carry practically equal portions of the load. Since the beams are of nearly equal depth, the stresses should be in the same order of magnitude.

A check of the final stresses in the outside and interior beams yields the following results.

Interior Beams (14CB370)		Top Flange	Bottom Flange
Bending Dead + Live Loads	$\frac{M}{S} = \frac{983{,}300 \times 12}{608.1}$	= −19,400	+19,400
Bending • Buffing	$\frac{M}{S} = \frac{130{,}960 \times 12}{608.1}$	= − 2,580	+ 2,580
Direct Buffing	$\frac{P}{A} = \frac{35{,}710}{108.78}$	= − 330	− 330
	Total Stress	= −22,310 p.s.i.	+21,650 p.s.i.

These stresses are within the working unit stresses selected for the design.

The mill test of the material in these beams gave a yield point of 43,740 pounds per square inch for which a calculation of the actual factors of safety may be of interest.

For Dead and Live Loads $F.S. = \frac{43740}{19400} = 2.25$

For Dead, Live and Buffing Loads $F.S. = \frac{43740}{22310} = 1.96$

Outside Beams (14CB426)

			Top Flange	Bottom Flange
Bending Dead + Live Loads		$\frac{M}{S} = \frac{983{,}300 \times 12}{S} =$	—17,800	+21,390
Bending	Buffing	$\frac{M}{S} = \frac{130{,}960 \times 12}{S} =$	— 2,370	+ 2,850
Direct	Buffing	$\frac{P}{A} = \frac{35{,}710}{115.17} =$	— 310	— 310
		Total Stress	—20,480 p.s.i.	+23,930 p.s.i.

The stresses for dead and live loads are well within the working stresses and only in the case of the bottom flange, when the buffing stresses are added, is the combined stress higher. The mill test material in the 14CB 426 beams gave a yield point of 42,140 pounds per square inch which leads to the following factors of safety:

For Dead and Live Loads $F.S. = \frac{42140}{21390} = 1.97$

For Dead, Live and Buffing Loads $F.S. = \frac{42140}{23930} = 1.76$

The stress of 23,910 pounds per square inch might have been reduced by the addition of an extra reinforcing bar for the short distance at the center where the stress exceeded 23,000 pounds per square inch, but since the actual yield point provided a factor of safety of 1.76 it was considered unnecessary to do this. Then too, the end deflection of the bolsters tends to relieve a small amount of the stress in the outside beams.

Since the sections of the beams at the center are maintained outward to the splices, the next cross-section of the car that should be examined is that just outside of the splices at Points B. It is evident, from a comparison of the sections that the curved section (D = 18 inches, to match the depth of a 14CB370 beam) is more than equivalent to a 14CB370 beam. Hence the interior beams will be adequate at the cross-section under discussion. The lower end of the curved section of the outside beams was made 18¾ inches to match the 14CB426 beams. No reinforcing plate was provided and some question might arise as to the stresses in the outside beams in the region of the
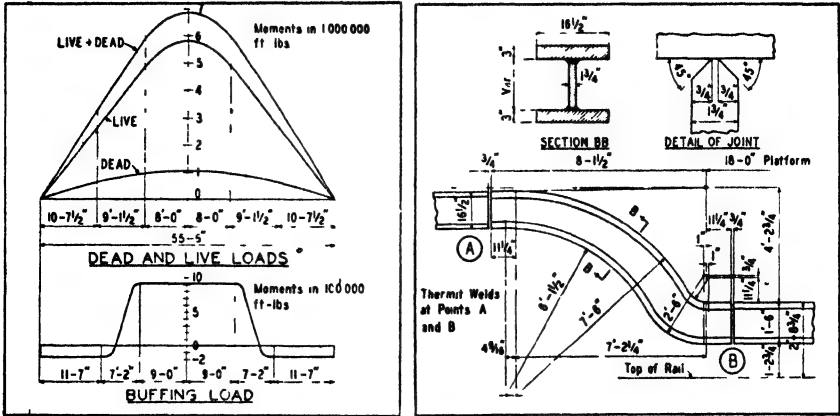
Fig. 5, (left). Moment diagrams. Fig. 6, (right). Curved section of inside beams.

splices since the bottom flange had to be trimmed to keep the structure within the clear diagram. The calculations will not be given but the stresses are tabulated below:

	Top Flange	Bottom Flange
Bending Dead and Live Loads	—15,670	+21,040
Bending Buffing	— 2,430	+ 3,260
Direct Buffing Load	— 340	— 340
	—18,440 p.s.i.	+23,960 p.s.i.

The mill test of the 3-inch plates in the flanges showed a yield point of 50,330 pounds per square inch which gives an actual factor of safety $= \frac{50330}{23960} = 2.10.$

Fig. 6 shows the dimensions and construction of the curved section of the inside beams, and the outside beams were practically the same except for the depth at the splice B. The stresses around the curved portion with the inner radius of 11¼-inches had to be investigated. The calculations were made in accordance with the principles of analysis for Curved Bars as discussed in "Strength of Materials Part II Second Edition 1941" by S. Timoshenko. They are somewhat involved but lead to the following results for the inside beams:—

	Top Flange	Bottom Flange
Bending Dead and Live Loads	—18,990	+12,890
Bending Buffing Load	— 3,040	+ 2,060
Direct Buffing Load	— 300	— 300
	—22,330 p.s.i.	+14,650 p.s.i.

Had the stresses been calculated on the basis of the section being in a straight portion of the beam the results would have been thus.

	Top Flange	Bottom Flange
Bending Dead and Live Loads	—14,970	+14,970
Bending Buffing Load	— 2,400	+ 2,400
Direct Buffing Load	— 300	— 300
	—17,670 p.s.i.	+17,070 p.s.i.

This indicates that the effect of the curvature was to increase the stress about 27 per cent in the flange on the inside radius of 11¼ inches.

In the case of the outside beams, the partial removal of the bottom flange benefits the stress in the top flange because it has the effect of moving the center of gravity of the section nearer the top. The total stress in the top flange is —13,740 pounds per square inch and in the bottom flange +11,990 pounds per square inch. Obviously, some reduction of weight might have been made here, but, for purposes of uniformity, the material was maintained the same as for the interior beams.
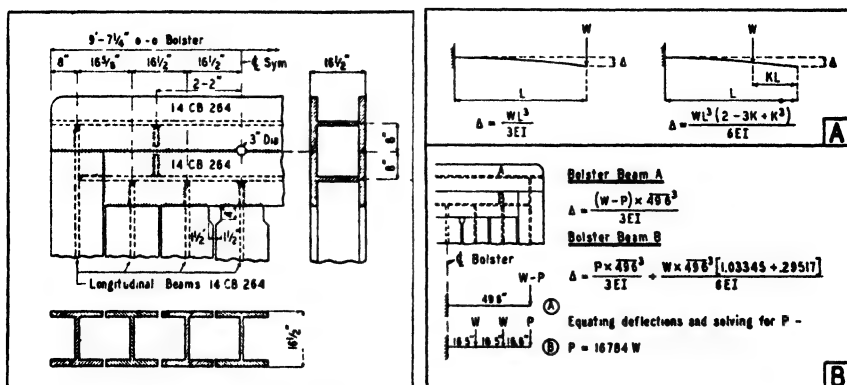
Fig. 7, (left). Bolster construction. Fig. 8, (right). Deflection of bolster.

The horizontal and portions of the car body were investigated at the splice at Point A, where the moments are as tabulated below:

	Car Body	Per Beam
Dead Load	654,130 ft.=lbs.	93,450 ft.=lbs.
Live Load	2,656,250	379,460
Total	3,310,380	472,910
Buffing Load	—171,880	—24,550
Total	3,138,500	448,360

Required Section Modulus

Dead and Live Loads $S = \frac{472{,}910 \times 12}{21{,}500} = 263.9$

Dead, Live and Buffing Loads $S = \frac{448{,}360 \times 12}{22{,}250} = 241.8$

Sect	I	Arc	Length
B	4754		
C	4935	BC	12 1/8"
D	5403	CD	12 1/8
E	5895	DE	12 5/8
F	6411	EF	13 1/2
G	6949	FG	15
H	7512	GH	18 1/4
I	6623	HI	18
J	5895	IJ	12 1/4
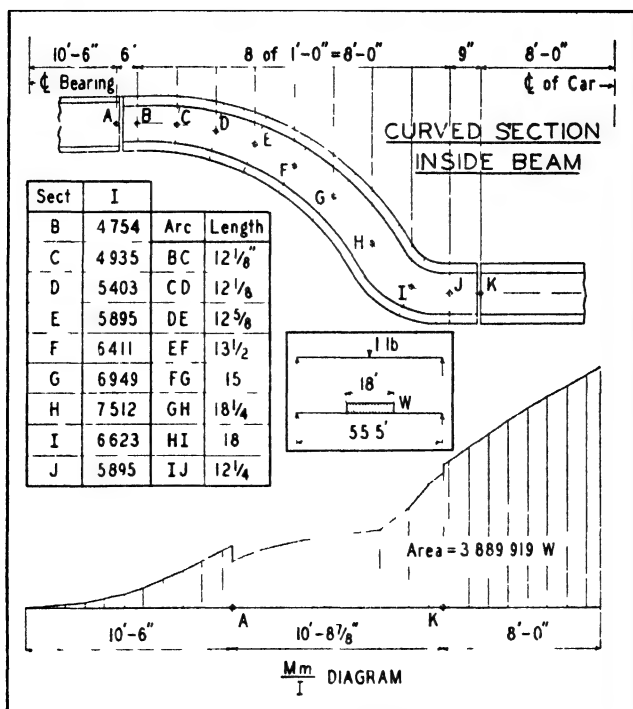
Fig. 9. Live load deflection.

The greater section modulus of 263.9 calls for a 14CB167 with S = 267.3.

The beams in the car, as actually constructed, were 14CB264 which were much heavier than were needed in the final design. This resulted from an earlier arrangement employing only six beams with the splice point A nearer the center of the car. The heavier size was inadvertently carried over to the final design and before the change could be incorporated, it was too late to do so without considerable delay. The decision was made to let the design go in the heavier size, since, quite obviously, the strength of the structure was not impaired. Again, this emphasizes the urgent need of speed in the delivery of the car.

The bolster construction is shown in Fig. 7. A double-beam bolster was used in order to provide a more uniform support for the 24-inch center plate than would have been the case with only one web over the center. For ease of fitting the seven longitudinal beams into the bolster and to keep a uniform depth of structure at this point, the same section of 14CB264 was used. This also permitted the rolling of the longitudinal and bolster beams from the same ingot, as there was not nearly enough weight in the bolster beams alone to utilize an entire ingot, as would have been necessary had they been rolled to a lighter section. Of course it was possible to build up the bolsters in the same manner as was done for the curved sections and thus to design a section to meet the requirements with a minimum of weight, but this was ruled out in this case, because of the extra preparation and welding necessary to achieve the equivalent of a beam section that could be rolled in one piece.

To complete the design of the car body, the calculations will be given for the bolster as it might have been constructed. Following out the same procedure and reasoning as in the previous paragraph, the two bolster beams might have been 14CB167 to match the longitudinal beams that were actually required, as it will be seen presently that they would have possessed ample strength.

From an inspection of Fig. 7 it will be noted that the outside longitudinal beam is connected to both of the bolster beams while the interior longitudinal beams connect only to the bolster beam nearer the center of the car. This brings about an indeterminate distribution between the bolster beams of the reaction of the outside beam unless some assumption is made. The assumption was made that the deflections of the two bolster beams were the same at the line of the outside beam. The calculations on this basis are developed in Fig. 8. Each half of the bolster may be treated as a cantilever beam and the formulae for end deflection of a cantilever beam are given in Fig. 8A.

From the loading diagrams of Fig. 4 the end reactions are readily computed with these results:—

	Reaction
Dead Load	71,385
Live Load	250,000
Total	321,385 lbs.

The total reaction per beam equals $\frac{321385}{7} = 45912$ pounds which is the value of W in Fig. 8B. Let P equal the portion of the reaction of the outside beam that is carried by Bolster Beam B. Then W-P is the load at the end of Beam A. Since the two bolster beams were to be of the same size, their moments of inertia were equal. The two equations for deflections of beams A and B are given and by equating them (the deflections were assumed equal) the value of P becomes .16784 W.

$$P = .16784 \times 45912 = 7706$$
$$W - P = 45912 - 7706 = 38206$$

The maximum moment in Beam A equals 38206 x 49.6 = 1,895,020 inch-pounds. The moment in Beam B equals (7706 x 49.6) + 45912 (16.5 + 33.0) = 2,654,860 inch-pounds.

It is customary practice to reduce the working stress 25 per cent when designing bolsters, hence the unit stress = 21,500 x .75 = 16,125, say 16,000 pounds per square inch. Using the larger of the two moments:—

$$\text{Required } S = \frac{2{,}654{,}860}{16{,}000} = 165.9$$

A 14CB 103 beam (S = 163.6) would be just about right as far as bending is concerned but it has a depth of only 14.25 inches whereas the longitudinal beams 14CB167, that might have been used, are 15.12 inches deep.

The maximum shear on the web of Beam B equals 7706 + 2 x 45912 = 99530 pounds. The shearing yield point of the nickel-copper structural is about 65 per cent of the yield point in tension, or, in this instance, .65 x 42000 = 27300 pounds per square in. Applying the factor of safety of 1.875 and

reducing the unit stress 25 per cent for bolsters, the working unit stress in shear becomes $\frac{27300 \times .75}{1.875} = 10900$, say 11000 pounds per square inch.

The required web area is $\frac{99530}{11000} = 9.05$ square inches. A 14CB127 beam has a web area of 8.91 and would therefore be acceptable, with a unit shearing stress of 11170 pounds per square inch. It is seen that shear and not bending is the controlling factor for these particular beams.

The bolster might have been fabricated from plates to a depth of 15⅛-inches to match that of the 14CB167 longitudinal beams. Such a built-up beam, having 15-inch x ¾-inch flange plates and a ⅝-inch web would have the following properties:—

I = 1295.1 S = 171.3 Web Area = 9.45 Wt. per ft. 106 pounds (incl. welds) This section meets all the requirements for both shear and moment.
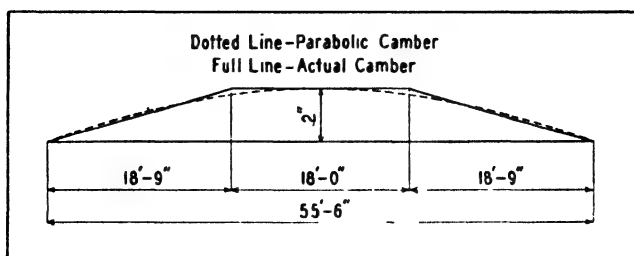
Fig. 10 Camber diagram.

As this paper presents an actual structure, it seeks to describe what was done and also to point out what might have been done. The end sections, outward from the splice points A, are the only portions affected to any extent. Summing up the previous discussion:—

	As Built	Possible
Longitudinal Beams	14CB264	14CB167
Bolster Beams	14CB264	14CB127 or Built-up @ 106 pounds

Deflection—The deflection of the structure was of practical importance and the method of calculation is shown in Fig. 9. The details of the computations will be omitted. The curved portion of an inside beam is shown and a table of properties at sections A to K and the distances between them as measured along the axis of the beam. The illustrative example is for the deflection at the center for a total load W, uniformly distributed over a length of 18 feet.

The principle for obtaining the deflection is to be found in many textbooks on Strength of Materials and consists first of finding the area under a curve plotted from the values of $\frac{Mm}{I}$ at a series of points along the span where

M = moment at the section from the given load
m = moment at the section from a unit load at the point where the deflection is desired
I = moment of inertia of the beam at the section

For example, take the section at B.

$$M = \frac{W \times 11}{2} = 5.5W \text{ ft. lbs.}$$

$$m = \tfrac{1}{2} \times 11 = 5\ 5 \text{ ft lbs}$$
$$I = 4754 \quad \text{(See Table in Fig 9)}$$

$$\frac{Mm}{I} = \frac{5.5\ W \times 5.5}{4754} = 0063\ 6306\ W$$

The complete diagram for one-half the total span is plotted in Fig. 9 from a series of calculations at one foot intervals, for the most part, measured horizontally. The actual distance between the sections of the curved portion of the beam are used as the abscissae in the diagram.

The procedure of calculating the area of the diagram will be clear and the result is 3.889919 W. The deflection is found from the following formula:—

$$\Delta = \frac{\text{(Area of Mm Diagram)}}{I} \times \frac{1}{E}$$

For the loading of Fig. 9

$$\Delta = \frac{3.889919\ W \times 2 \times 144}{29000000} = .0000\ 3863\ W$$

The figure 2 in the numerator is required because the area of the diagram covers only ½ of the span and the 144 factor is necessary to convert the moments M and m to inch lbs.

W = 500000 pounds for the entire car and for one beam it is $\frac{500000}{7}$ = 71430 pounds. Putting this value for W in the above formula for the live load deflection —

$$\Delta = 0000\ 3863 \times 71430 = 2\ 76 \text{ inches}$$

From a similar calculation the dead load deflection was found to be 0.56 inch

When the car was finally built, it was loaded with plates to an actual load of 500,137 pounds at which there was a measured deflection of 2⅞ inches Comparing this deflection with the calculated value, it is seen to be within 4 per cent, thus affording an excellent check on the computations

By reference to Fig. 1 it will be noted that when the deflection of 2¾ inches is taken from the unloaded height of the platform, the height under full line load is 2 feet 6 inches—the requirement of the basic specifications.

A 2-inch camber was put into the car body in a manner shown in Fig. 10. This was done by dropping the outer ends of the horizontal beams, beginning at the limits of the platform Obviously no gradual curvature could

be put into the beams before assembly. It will be seen in the camber diagram that the actual method was in close practical agreement, however, with a theoretical parabolic camber.

One point about the deflection may be of passing interest. While the live load was assumed as uniformly distributed over the platform it would be impossible to get this loading with an ingot mold such as shown in Fig. 16. The mold is so rigid that it has practically no deflection in itself and therefore cannot conform to the elastic deflection curve of the car body beams. Hence, the car body would actually deflect away from the mold, thus transferring the loads outward toward the ends of the platform, with a consequent reduction of the maximum moments and stresses. As a matter of fact, the mold does not have a truly flat base and in loading it on the car, oak planks are placed under each end so as to be above the local surface irregularities on the under surface of the mold.

Shop Fabrication—The method of welding these five sections into one longitudinal beam had to be given serious thought for several reasons. A glance at the moment diagram of Fig. 5 shows that at splice points B there is not a great reduction from the maximum moment at the center. The reduction is only 19 per cent and called for practically 100 per cent efficiency in the splices. Another factor was the impossibility of stress-relieving the complete structure—first, because of lack of facilities of sufficient size and second for fear of distortion. Distortion from welding had to be guarded against because it was essential that each longitudinal beam have the same shape, in order that the platform would be smooth and level after final assembly. Matching of the shape of all seven beams was necessary in order to carry out the welding of the flanges. It would not have been possible to correct any irregularities in the welded beams to achieve this uniformity without great difficulty.

The weights and sizes of the parts to be handled were also a factor to be considered. The weights for one interior beam are tabulated below:—

1—Platform Section @ 5970	=	5970 lbs.
2—Curved Sections @ 4360	=	8720
2—End Sections @ 2485	=	4970
Total Weight of One Beam	=	19660 lbs.

The length of this assembled beam was about 56 feet and with the ends curved upward to an offset of 4 feet 3 inches, the assembly would have been an awkward and heavy piece to position for arc welding on all four sides of the splice. It would have been quite possible to design a jig in which the beam could have been rotated about a longitudinal axis, but since only one car was to be built, the expenditure for such a jig for special handling was not warranted.

An excellent solution of the problem of making these splices was offered by Thermit welding. Because the weld is made in one operation, the heating and subsequent shrinkage are uniform across the section. The mold around the joint provides for slow cooling, which is practically a stress-relieving process, resulting in a minimum of locked-up stresses. The fact that the beam sections at the splices were nearly alike in all cases made it possible to use the same molds (with minor variations) for all 28 joints, thereby resulting in a good production job.

No particular problem was involved in the construction of the curved sections. The webs were cut to shape by a gas torch, mechanically guided

Fig. 11, (left). Jig and assembly for welding. Fig. 12, (right). Welded joint after removal of mold.

from a track template The edges were then beveled as indicated in the detail of the joint in Fig 6 The 3-inch top and bottom flange plates were heated and bent to shape in small dies on a gag press and checked against a template The straight portions at the ends were necessary in order to avoid the difficulty of starting a bend at an edge One other very practical consideration from the standpoint of design in connection with the straight end portions was the resulting location of the splices outside the region of increased stresses due to the curvative of the beam.

The web and flanges were assembled in a simple jig and welded together in eight alternate passes on each side of the web. Three-quarter inch fillets were then built up on top of these welds in six passes on each side. Since the welding was carried out in a cold shop during January 1941, the steel was kept warm with gas flames

Fig 11 shows the jig and arrangement for assembling and thermit welding the longitudinal beams An I-beam was used as a temporary base to which were tack welded short lengths of small beams to support the platform portion of the car body beam and the lower ends of the curved sections. The straight end portions of the curved sections were convenient for placing a horizontal support under them. The higher portions were supported on posts cut from scrap beams to which angles were welded to form a bearing under the longitudinal beam. The jig was simplicity itself. The camber was put into the complete beam assembly by lowering the outer ends of the upper horizontal portions 2 inches below the level at the line of the platform. This simple means avoided any clamping or jacking operations.

The picture shows one of the interior beams of the main car body. Each of the five parts was assembled in its proper place and the molds were placed around the four splice joints. This operation required a day's time. On the second day, the joints were preheated, two at a time, and then poured. In the meantime, another beam was assembled on a second jig and the fabrication alternated from one jig to the other. Under ordinary circumstances, it would not have been necessary to build a second jig but it saved a week's time at only the small cost of the extra jig.

Fig. 12 shows two of the joints after removal of the molds. Subsequently, the reinforcing was chipped and ground along the edges of the flanges and smoothed over the remaining portions of the joint. It is interesting to note

that the overall movement of the beams, after the four splices had been poured and cooled, was negligible. This assured the matching of the seven beams when assembled side by side in the car body and obviated any need for adjustment.

Prior to the assembly of the car body, intermediate plate stiffeners at 3′0″ ctrs. in the platform portion only were welded to the web between the flanges on both sides of three interior beams. These stiffeners projected beyond the flanges of the beams to which they were welded so as to act as stiffeners between the flanges of the adjacent beams. Because of the boxed-in condition it was impossible to weld the stiffeners to the adjacent beams. The intended function of these stiffeners was to brace the top flanges against local bending from the load applied directly to them.

The next step in the fabrication was the assembling and welding together of the seven beams comprising the main car body. The ends of the beams are framed into the double-beam bolsters as shown in Fig. 7. When finally fabricated, the top and bottom flanges of the beams in the platform and curved portions were securely welded together as indicated in Fig. 2. J-butt welds were used in order to avoid moving all the heavy pieces to a machine for preparation of the groove, since the placing of a groove in each edge of the flanges of only three beams provided grooves for welding all of the beam flanges together. This grooving was done on the individual units of the beams before the thermit welding of the splices was carried out. The grooving of the curved flanges was done before the plates were bent to shape. The photographs of Figs. 11 and 12 clearly show the prepared edges.

The weight of the completed main car body was about 150,000 pounds. Welding of both top and bottom flanges called for some means of turning
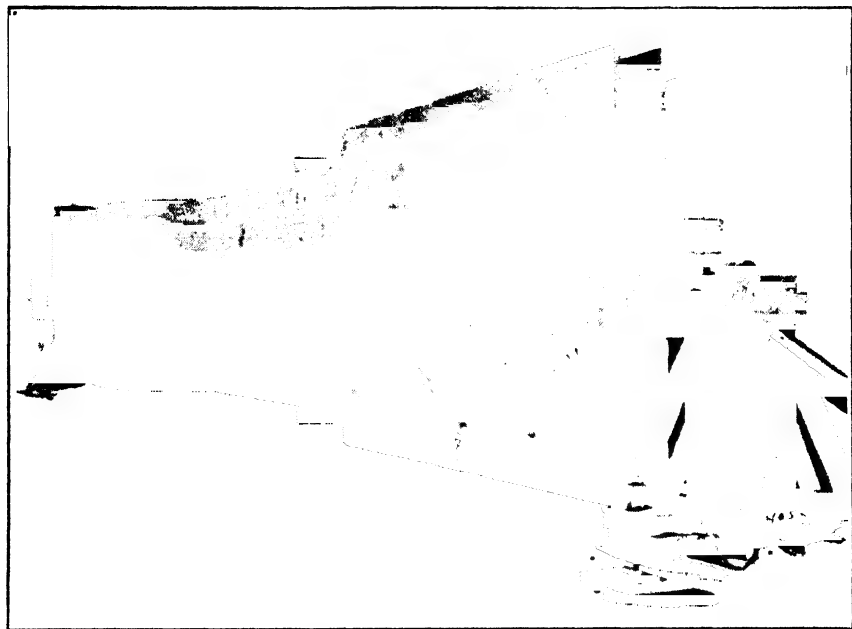
Fig. 13. Jig for assembly of car body.

the heavy structure so that the work could be positioned for welding. Two jigs with trunnions and clamps for holding the bolsters at each end were constructed and are shown in Fig. 13. Since the connections of the beams to the bolster are boxed in by the addition of the next beam it was necessary to start with the assembly of the middle beam and weld it to the bolsters at each end. Then the beams on either side were assembled and welded to the bolster until, finally, all seven beams were so connected.

Next came the making of the continuous longitudinal welds on the flanges of the beams in the platform and curved sections Owing to the fact that the fabrication of this car was carried out in freezing weather of January 1941, a rough wooden shed was built in which the assembly and welding could be conducted. The entire assembly was maintained at about 200°F. throughout this welding operation by means of several gas fires inside old steel drums, which were distributed along the under side of the car body. By a careful control of the heat it was possible to keep warping to a minimum. Gages were distributed at several points, by means of which the deflection due to welding on the top side could be measured. Whenever this deflection amounted to ½-inch, the assembly was turned over and welding proceeded on the opposite side until the deflection indicated that another reversal should be made. Once the welding had begun, the operation was carried on continuously until the work was completed. The step-back method was followed and symmetry of welding about the center line of car was maintained in order to avoid unequal warping.

Upon completion of the longitudinal seams, the positioning fixtures were temporarily removed to permit the addition of the outside end beams forming the other half of the bolsters. The fixtures were replaced so that the final welding of these end beams could be completed and the body side bearings be positioned. The jigs were then removed and the center plate riveted and welded in place.

From this stage on, the assembly of the car was completed by placing the main car body on the two end supporting structures. There was no crane available with sufficient lifting capacity and to surmount this difficulty the assembly and welding of the main car body had been carried out over one of the yard tracks. The body was jacked up while the two end structures on their trucks were rolled into position, when the main body was lowered into its final position
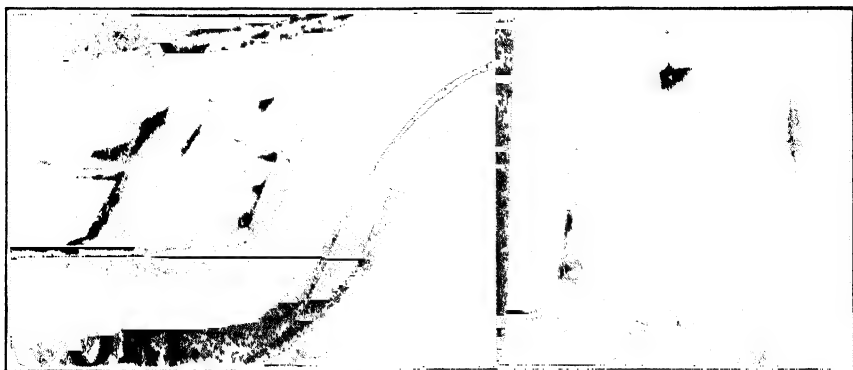
Fig. 14. (left). View of welded splice. Fig. 15. (right). Longitudinal welds on curved section.

The fabrication of the main body required 8000 pounds of Thermit in the making of the 28 splices. There were 38400 linear feet of ¼-inch bead welding, requiring 7800 pounds of electrodes and 1400 man-hours for the operators.

Fig. 14 is a photograph of the thermit-welded splice between the platform and curved portions. The fillet weld between the web and flange of the curved section is plainly evident. Likewise, the beveling of the bottom flange to bring it within the A.A.R. clearance diagram may be seen Fig. 15 shows the longitudinal welds on the flanges of the curved portion.

Fig. 16 is a photograph of the completed car carrying its first load, an ingot mold weighing 160 tons. Today the car is in regular use, contributing its share to the war effort of the steel industry.

Advantages of Welding—The problem of riveting such a car body appeared almost insurmountable and the only other alternative to welded construction was that of unit cast steel. This latter method would have involved the cost of an expensive pattern, which cost would have had to be absorbed on the one car. Then there was the delay incident to making the pattern, whereas the welded construction could start immediately upon arrival of the rolled steel at the shop. Welded construction offered the assurance of sound metal throughout the structure and precluded any possibility of delay or expense due to difficulties that might arise in pouring so large a casting

A brief study of the construction of the main car body will show that, aside from the one operation of bending the flange plates of the curved sections, every other operation can be executed with the simple tools and equipment used in gas cutting and welding There is no need to handle any of the pieces to machines for any of the operations common to riveted work.

Where shop overhead expense is proportioned according to the facilities required in fabrication, it becomes apparent what savings can be effected in the cost of welded construction of the type exemplified by this car.

The jig for the Thermit welding was particularly simple and inexpensive, since it merely had to provide vertical support for the weldment and was not required to restrain any deformation or provide for positioning the beam. Very few shops, particularly in the car building industry, are
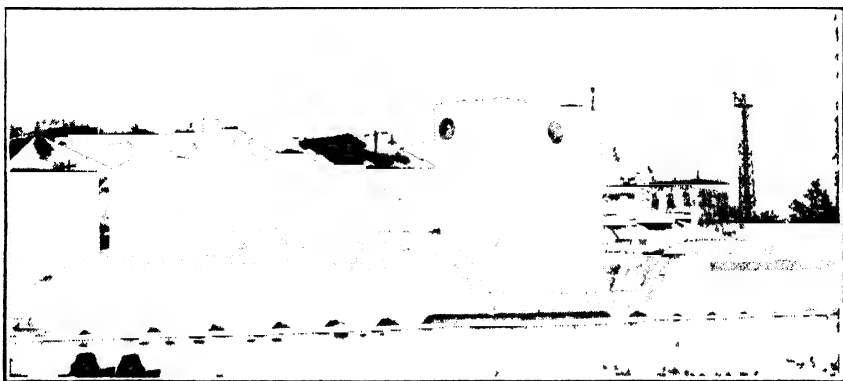
Fig. 16. Car loaded with 160-ton mold.

equipped with cranes of sufficient capacity to lift 75 tons and, in overcoming this difficulty, the jig for the car body met the problem of assembling and handling for welding in an effective manner.

Estimates of Cost—The actual costs of the main car body were available only in part to the author and it has been necessary, therefore, to estimate a cost for a minor portion of the total: No car of this size has ever been built in cast steel construction and consequently there are no figures for the cost of such a car.

WELDED DESIGN

Item	Cost
Rolled Steel (including freight)	$ 5980
Arc Welding	
Material	520
Power	200
Direct Labor	1650
Thermit Welding	
Material	2800
Direct Labor	500
Jigs	1300
Preparation of Material	
Labor	750
Total Cost	$13700

The weight of the finished car body was 156,980 pounds. The cost per pound equals $\frac{13700}{156980} = \$.0873$. The addition of 150 per cent overhead to the items of labor brings the estimated cost to $18,050, or $.1150 per pound.

A still further reduction in the cost of the welded rolled steel design might have been effected by using ordinary structural steel instead of the nickel-copper steel in the high end beams, the webs of the curved portions and the stiffening plates. This would have resulted in a reduction of .50 cents per pound in the cost. Such use of lower cost material in places where it is suitable could not be followed with cast construction, since it would be necessary to pour the same grade of material throughout the casting.

Cast Steel Design—From a study of the published prices of cast steel truck bolsters, locomotive side frames and complete locomotive beds in standard designs (for which no large costs for new patterns have to be included) it has been concluded that the price of the main car body in cast high-tensile steel would have been at least 15 or 16 cents per pound.

Summary of Costs

Material of Construction	Cost	Profit	Price
Welded Rolled Steel	11—11.5c	20%	13.2—13.8c per lb.
Cast Steel	....	....	15.0—16.0c per lb.

Since only the selling prices of cast steel were available, it was necessary to determine a selling price for welded rolled steel, for which a profit of 20

per cent has been assumed. The comparison of prices shows a definitely favorable balance for the welded rolled steel construction.

Conclusion—This paper has described the design and construction of a special type of car, of which only one was built. In the case of most special cars, only a single unit, or at the most only a few are built to any one design. For such cars, welded rolled steel construction offers an ideal method of fabrication at a reasonable cost and facilitates prompt completion.

The designing and fabricating procedure and the simplicity of construction details developed for this 250-ton flat car point definitely to the advantages of applying them to the underframes of ordinary flat cars and gondolas, where the number of cars of these types, built annually, runs into the thousands Underframes of box cars are already in that class where welding is an accepted method of fabrication.

As might be expected, retrospective study and analysis of the design of this car, in the light of experience, have brought out several instances where additional economies may be effected in the cost of future cars. No detail of construction is too small to be studied and the success of any welded structure is enhanced to the degree that attention is given to seemingly minor items of design and fabrication.

Chapter V—Arc Welded Conversion of Tenders Into Tank Cars

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Clifford A. Salk

Subject Matter: Arc welding, applied to the conversion of tenders into tank cars, lengthens the service life, since corrosion causes rivet heads to loosen and plates to crack. Corrosion can be more readily checked if welding is employed and the car is stronger and more durable Further, the elimination of excess material reduces the total weight and gives better and longer performance. Arc welding offers a larger measure of safety both during construction and in subsequent operation, since there are no projecting rivet heads on plate edges to trip trainmen and loaders walking on the deck. Savings 24%, as compared with riveting, are claimed

Ray F. Theisen

The subject matter of this paper compares arc welding with the previous method of construction which was riveting.

Referring you to "Bill of material for riveting one Water Car, changed from a Tender," and "Bill of material for Arc Welding one Water Car, changed from a Tender," herein attached: The total cost of construction by applying rivets, was $130.03, and the total cost of construction by applying arc welding is $97.92, a saving of $32.11, or 24.7 per cent per water car.

The total time for riveting was 60.8 hours and the total time used for arc welding is 24 hours, a saving of 36.8 hours, or a saving of 60.5 per cent of time. Welding speeds production! Figures don't lie!

Referring to drawings Figs. 1 and 2, you will readily notice the difference in the tank supports used. Where riveting was applied, we used a long angle iron, and where we applied arc welding 1-inch bars were used. We found arc welding made a sturdier, stronger and more rigid structure. Where the angle iron was used we found loosened rivets due to vibrations. By use of arc welding, this fault was readily checked. When these rivets were loose, we also found the plates to which they were attached, cracked, causing the tank to leak.

On car after car, as we went along, we applied arc welding instead of rivets, in places where arc welding proved more practical, until finally arc welding was applied throughout, discarding the use of rivets altogether. On these water cars, all rivet heads inside of the car became corroded and rusted. Corrosion and rust caused the rivets to loosen which in turn cracked the plate to which the rivets were applied. On the other hand where arc welding was used, corrosion and rust can be checked, the service life of the car can be lengthened a great deal. Arc welding, therefore, definitely increases the service life of these water cars.
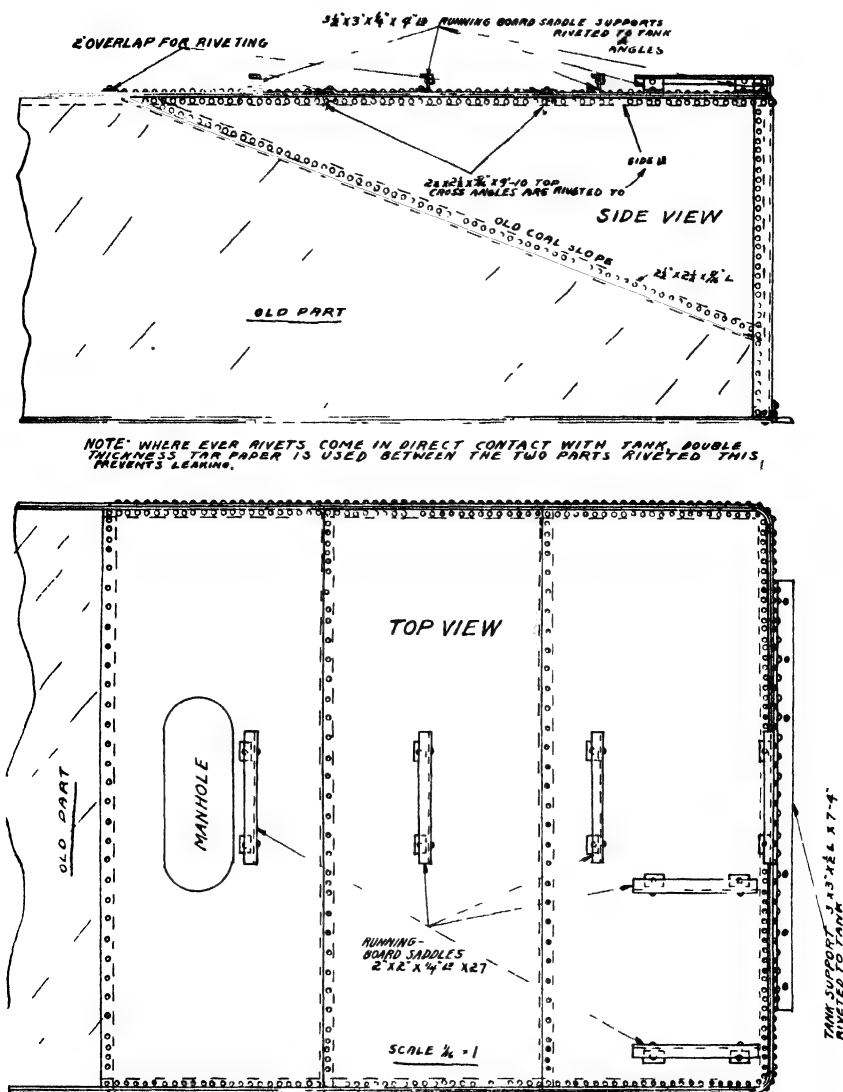
Fig. 1. Riveted conversion of tender into water car.

Arc welding has been proven more efficient than riveting: Referring to the drawings where the coal slope angles meet the top of the car, it was found rather difficult to get in those corners with a pneumatic riveting hammer, where therewith a welding rod, it could be easily reached. Therefore, arc welding is more practical and more efficient in the course of construction on these water cars.

In the actual structure, arc welding makes the car one integral part, stronger, more durable and more rigid. Plates and angles are weakened by the process of punching, which must be done preparatory to riveting.
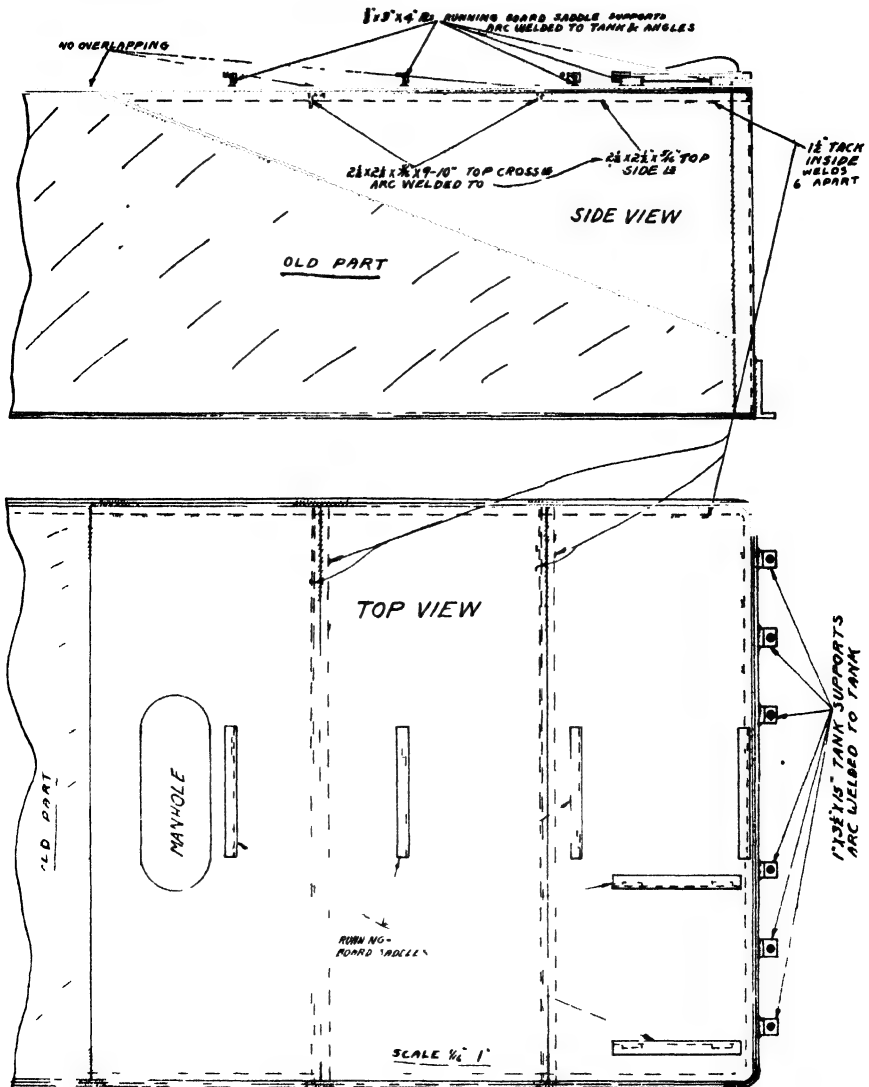
Fig. 2. Welded conversion of tender into water car.

Refer again to drawings, Figs. 1 and 2. Note the coal slope angles which are used when rivets are applied; when arc welding is applied, these angles can be done away with completely. Where extra material can be discarded, it makes the tank lighter and therefore gives the tank a better and longer running performance.

More safety can be accomplished in the course of construction and in the actual structure of water cars by the use of arc welding. The top of the water car or tank deck that is riveted, the plates attached must be overlapped to allow connection of these plates by the rivets. This overlap-

Bill of Material and Labor Required for Riveting One Water Car Changed from a Tender (See Fig. 1)

Angle Iron

				Total Cost
7'-4" Lin. Ft. 3"x3"x½"	@9.4# cwt. $2.77		$ 1.92	
4'-0" Lin. Ft. 3½"x3"x¼"	@5.4# cwt. $2.77		.70	
68'-10" Lin. Ft. 2½"x2½"x5/16"	@5.0# cwt. $2.77		10.99	
13'-6" Lin. Ft. 2"x2"x¼"	@3.19# cwt. $2.77		1.19	
	Total cost of angle iron			$14.80

Plates

3—Pls. ¼"x4'-0"x9'-10"	@401.2# cwt. $2.77	$33.44	
1—Pl. ¼"x4'-2"x11'-4"	@481.7# cwt. $2.77	13.34	
1—Pl. ¼"x5'-6¼"x10'-0"	@563# cwt. $2.77	15.60	
	Total cost of plates		$62.38

Rivets

22—5/8"x2"	@.249#	cwt. $4.17	$ .23	
13—5/8"x2¼"	@.273#	cwt. $4.17	.15	
74—½"x2¼"	@.163#	cwt. $4.37	.53	
825—½"x2"	@.149#	cwt. $4.37	5.27	
		Total cost of rivets		$6.18

Tarpaper

1—Piece 3'-0"x29'-0"	@$.004146 per sq. ft	$ .36	
	Total cost of material		$83.72

Labor

Angle Punching

906—9/16" holes 2 men, 2 hrs.	@$.72	$ 2.88	

Plate Punching

863—9/16" holes 2 men, 3½ hrs.	@$.72	5.04	
	Total cost of punching		$7.92

Cutting by Acetylene

200—9/16" holes 1 man, 1 hr.	@$.72	$ .72	

Riveting

2 men, 10 hrs.	@$.60	$12.00	
2 men, 10 hrs.	@ .88	17.60	
	Total cost of riveting		$29.60

Bolt Tacking, Preparatory to Riveting

2 men, 2 hrs.	@$.88	$3.52

Reaming Holes Preparatory to Riveting

1 man, 1½ hrs.	@$.88	$1.32

Application of Tank Supports

2 men, 20 min.	@$.88	$ .59

Application of Coal Slope Angles

2 men, ½ hr.	@$.88	$ .88

Application of Tarpaper

2 men, 1 hr.	@$.88	$1.76	
	Total cost of labor		$46.31

TOTAL COST OF MATERIAL AND LABOR $130.03

Note: All other labor is same as for arc welding.

Bill of Material Required for Arc Welding (Manual)
One Water Car Changed from a Tender (See Fig. 2)

Item	Weight	Price	Cost	Subtotal	Total Cost
	Angle Iron				
44′–10″ Lin. Ft. 2½″x2½″x5/16″	@5#	cwt $2.77	$ 7.11		
13′– 6″ Lin. Ft. 2″x2″x¼″	@3.19#	cwt. 2.77	1.19		
	Total cost of angle iron				$ 8.30
	Plates				
2—Pls. ¼″x4′–0″x9′–10″	@401.2#	cwt $2.77	$22.30		
1—Pl. ¼″x42″x9′–10″	@351#	cwt 2.77	9.71		
1—Pl. ¼″x5′–6¼″x10′–0″	@563#	cwt 2.77	15.60		
1—Pl. ¼″x4′–2″x11′–0″	@467.5#	cwt. 2.77	12.94		
1—Pl. ⅜″x3″x4′–0″	@1.275#	cwt. 2.77	.14		
6—Pls. 1″x3½″x15″	@14.885#	cwt. 2.77	2.47		
	Total cost of plates				$63.16
	Welding Rod				
5/32″ F. W. No. 5—6#		cwt. $6.30	$ .38		
3/16″ F. W. No. 7—18#		cwt. 5.80	.94		
5/32″ F. W. No. 7—14¼#		cwt. 6.30	.90		
	Total cost of welding rod			$2.22	
	Total cost of material				$73.68
	Labor				
1 man, 24 hrs.		@$1.01			$24.24
TOTAL COST OF MATERIAL AND LABOR					$97.92

Note: All other labor is same as for riveting.

COMPARISON

Total of construction cost by using riveting	$130.03	
Total of construction cost by using Arc Welding	97.92	
TOTAL COST SAVED BY USING ARC WELDING		$32.11

ping makes a rough deck not as safe for trainmen and loaders, as an arc welded deck, where overlapping is not necessary and where protruding rivet heads are done away with, making a smooth even tank deck. Arc welding, as a whole, makes the tank one integral, solid piece, to insure rigidity and lessen destruction by vibration.

Arc welding is safer in the course of construction of these water cars. There are four men to a riveting crew, a rivet heater (with his furnace, tongs, buckets and water pail), a rivet catcher (with his bucking bars of all kinds to get into different places), and a hammer man (with his pneumatic hammer). In the course of riveting, the man that bucks rivets must have a wrench, reaming machine, and a hammer handy. A wrench to take out bolts, a hammer to drive rivets through holes that fit a little snug and a reaming machine to ream out holes that may be too small for the rivets. With all these tools, hoses and machines lying here and there it makes riveting much more hazardous than arc welding, which takes one man with one machine and his welding rods and ball peen hammer.

During the course of writing this paper these water cars were converted into oil cars, by simply adding a suction pump and vent pipes, thereby releasing the conventional type tank car for use in defense oil delivery.

In the course of constructing these water cars arc welding was more economical, more efficient, due to increased service life of the cars, safer in structure, less hazardous in the course of construction and it speeded up production.

Chapter VI—Underframes for All Welded Railroad Passenger Cars

By J. E. Candlin, Jr., and A. M. Unger,

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Pullman-Standard Car Manufacturing Co., Chicago, Illinois

J. E. Candlin, Jr.

Subject Matter: Major considerations in the gradually-increasing applications of welding to railroad passenger cars are outlined "since 1936." The standard construction for steel passenger cars has been the all welded car. Strength calculations and a discussion of the fabrication of various assemblies follows, including, especially, the draft sill and the end sill, for which steel castings were always formerly employed. Cost and weight comparisons are made showing substantial savings.

A. M. Unger

The American Railroads have been very successful in the handling of passengers with comfort and speed for they have always emphasized passenger safety. The careful design of railway passenger cars is the most important reason for the remarkable safety record that has been established. Before the era of light weight cars, safety was accomplished by the use of excess metal in the construction, but with the introduction of modern streamlined trains during the last decade, the premium placed on light weight construction would not permit an inefficient design to be used.

Reduced weight is now very important in the industry, since the railroads have been forced, by competition, to operate at the greatest possible efficiency, and the use of light weight equipment allows longer trains and higher scheduled speeds. During this last ten year period, many new materials have been made available for car construction and new methods of fabrication and assembly have been developed. The designer must choose the right materials for construction, use the proper amount of material to withstand the forces encountered, and assemble the material by the most efficient method.

Given the proper material, it is not enough to use the correct amount without providing sufficient connection between the various parts. Welding is the most important gift given the railway car designer for his use in producing a light weight steel car. In using this tool he can keep the cost of construction as low as possible by eliminating the use of expensive dies and machinery. The maintenance costs also are kept low due to the omission of lap joints which invite corrosion. He can design a structure that is welded into a unit instead of one which is a collection of parts. He can build a structure which has the exact properties he desires instead of using a rolled or pressed section which is available. As a result, the strength of the finished car can be increased when less material is used.

For many years, all structural parts of a railway passenger car, whether of rolled or cast steel, were riveted together. When welding was first introduced, it was used only on minor parts that carried no important loads.

As welding was developed, it soon proved economical in other parts of the car, and today very few non-welded parts are used. Even these are being replaced one by one with welded assemblies. Since 1936, the standard construction for steel passenger cars has been the all-welded car, (See Fig. 1.)

Specifications and Design—A railway car structure may be divided into two principal parts: the superstructure, that portion of the car which is above the floor line; and the underframe, that portion below the floor. The sides, roof and ends which compose the superstructure of the car were previously of riveted construction but are now all welded. For each side or end, the framing is all assembled by arc welding the rolled and pressed members together into a framework. All the sheets are arc welded together to form a covering for the framework. This large covering sheet is then spotwelded to the framework to form a finished side or end.

Welding has also replaced riveting in the underframe. The underframe is made up of many parts, the principal member being the "backbone" comprising the "centersill" and the extending portion of it which is called the "draft sill".

The latest item on the car to be changed to an arc welded design was the draft sill structure. The underframe must be designed to support the floor loads as well as the forces from adjacent cars which are continually pushing and pulling while the train is in operation. The design of the draft sill is a very important problem because of the high stresses involved and because the draft sill is subject to high impact and fatigue.

The need for a strong center sill construction always has been apparent and was recognized by the government in 1912 when the postoffice department approved the first "General Specification for the Construction of Steel Railway Post Office Cars". This document was the first general specification for construction of steel railway passenger cars and has been revised five times in a period of 26 years. The last revision was made in 1938. Although no general specification such as this was adopted by the Association of American Railroads during this period, the Post Office Specification was followed by the leaders in the car-building industry for the construction of all cars whether they were to carry mail or not. It was assumed, of course, that the protection of passengers was as important as the protection of mail

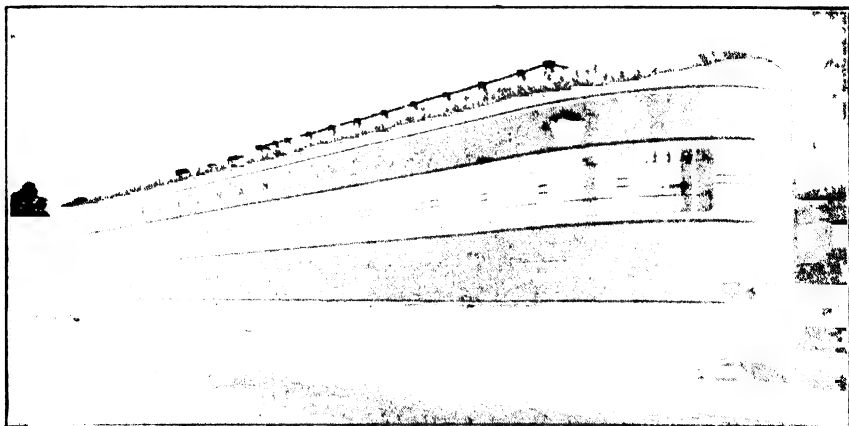



Fig. 1. Modern all welded steel passenger car.

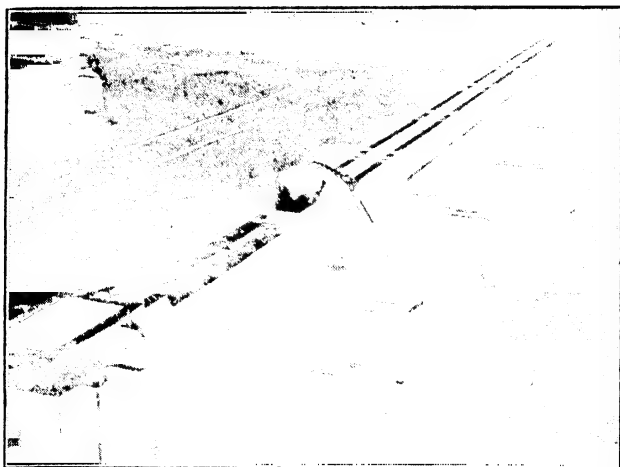



Fig. 2. Attached cast draft sill to center sill.

and mail clerks. Moreover, definite advantages could be claimed by making all cars in a train of equal strength.

With the above thoughts in mind, and in an effort to compel all railroads and car builders to build cars that would provide maximum safety, the Association of American Railroads adopted as recommended practice, in the latter part of 1939, "Specification for the Construction of New Passenger Equipment Cars". This specification was written to cover all cars operating in passenger trains, whether mail, express, baggage, or for passengers only, and, because it was by far a more rigid specification than that of the Post Office Department, this new set of rules was destined to affect the entire building industry.

For many years, previous to the adoption by the A.A.R. of their first code covering construction of passenger cars, welding was not generally used in the industry and the railroads had a choice, for the important draft sill, of using a construction of rolled steel in riveted form or a huge steel casting. The riveted structure, while considerably lighter and less expensive than the casting, was of ample strength to meet the then existing rules for construction. Experience in operating cars over a long period has shown the riveted type of construction to be well engineered for passenger safety. The cast draft sill was, of necessity, penalized in weight and cost because it was impossible to make a casting with very thin walls. The additional metal used was also necessary because of the allowance that must be made for porosity in a casting. (The A.A.R. specifications state that the allowable tensile stress of cast metal shall be limited to 80 per cent of that allowed for rolled metals.)

Just before the new A.A.R. rules took effect, some welding was used in the draft sill but this was limited to attachment of castings to rolled sections and plates. The engineer designed the center sill to run all the way to the end of the car and supplemented it with a few steel castings. In this way the draft sill became an integral part of the center sill. This was possible because at that time a buffing device was used to relieve the coupler of a portion of the buffing load.

After the adoption of the A.A.R. specification which provides for the

use of tight locking couplers without a buffing device, it was necessary to add great strength to the draft sill which addition would probably double the weight of this member This large addition in weight allowed the cast construction to compete on an equal basis with the riveted construction, in fact, the engineer found it difficult to provide sufficient rivets to meet the required strength The steel casting, although heavier, could easily be made to comply with the new requirements and was used on several of the succeeding designs, (See Figs 2 and 3)

After an analysis of various types of construction and materials, it became evident that welded assemblies would provide outstanding advantages and that an entirely arc welded draft sill could be designed, which would be stronger, lighter, and less expensive than either a riveted or cast sill The introduction of the modern low alloy, high tensile steels made the welded draft sill a much better construction than a cast draft sill because of the additional saving that could be made due to use of this steel Fig 4 shows an all welded alloy steel draft sill.

A.A.R. Specifications—Since the A A R specifications are new to many men in the business, the following will serve to explain briefly, the main points to be considered The strength requirements for the draft sill can be summarized as follows

1 The draft sill should stand a horizontal load of 800,000 pounds applied at the rear stops on line with the center of the coupler without permanent deformation This force represents the maximum load on the coupler (This load is actually applied in a "squeeze test" which is sponsored by the Association this test to be made on all new designs)

2 It should resist a horizontal load of 500,000 pounds applied on its

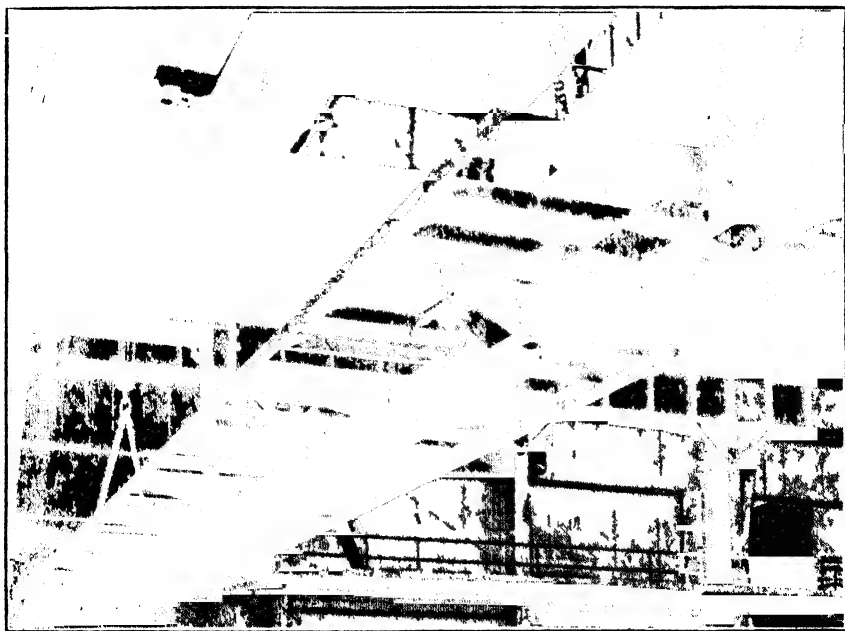



Fig. 3. Completed underframe with cast draft sill.

extreme end at a point 12 inches above the coupler line. This portion of the sill is called the "center end sill". This force represents the maximum load on a "buffing device" that is sometimes used at this location.

3. The center end sill should resist an upward thrust of 100,000 pounds at any position the coupler may take. The center end sill is made to extend almost to the centerline of pulling face of the coupler so that a conventional coupler on the adjoining car cannot slide vertically upward to disengage. This arrangement meets the anti-climbing requirements of the specification.

4. The coupler carrier should stand a vertical downward load of 100,000 pounds applied at any coupler position. The carrier is actually spring suspended but the member just below it may be made to meet this rule.

5. The body centerplate should be attached so as to resist a force of 250,000 pounds applied in any direction. This represents the force that should be set up by the truck in resisting telescoping of the cars.

6. Each main vertical end post should be of sufficient shear area and should be attached to the end sill so as to resist a horizontal load of 300,000 pounds. These posts are anti-telescoping members and together they afford a resistance of 600,000 pounds.

Referring to items 1, 2, and 6, above, it is evident that the draft sill must be designed to stand a load of approximately 800,000 pounds applied on its end in almost any position. This accounts for the serious addition in weight over the old designs where this force was applied at one point only.

7. All vertical reactions due to any of the above forces or moments may be resisted by the bolster.

Method of Calculating—For the first two parts of the specification (in 1 and 2 above), it was found, on very careful analysis, that the following method of calculation would apply:

Let F = Fibrestress at extreme fibre of section.

St = Section modulus at top of section.

Sb = Section modulus at bottom of section.

S = Minimum section modulus.

A = Area of section.

The stress at any section due to the load of 500,000 pounds applied 12 inches above centerline of coupler

$$F = \frac{500{,}000}{A} + \frac{500{,}000\ Y}{St}$$

The stress at any section between the centerline of bolster and rear draft lug due to the load of 800,000 pounds applied at the rear draft lug

$$F = \frac{800{,}000}{A} + \frac{800{,}000\ X}{Sb}$$

The stress at any section between the rear draft lug and the centerline of end post due to the 800,000 pound load

$$F = \frac{800,000\ Z}{S}$$

The above formulas, when used so as to give stresses below the yield point of the material by sufficient margin for safety in the so-called "squeeze test" referred to previously, will give the plate thickness necessary to form a satisfactory draft sill. Of course, detailed study must be made of the following points:

(a) The center of gravity of the centersill should lie in approximately the same horizontal plane as the center of gravity of the draft sill so that no moments will be set up at the splice between these two members. Where no eccentricity exists at the splice, the bending moment in the sill at the bolster is very low because of the great stiffness of the draft sill. This small moment can be ignored.

(b) The draft lugs should be checked carefully to make sure that they are backed up by sufficient ribbing so that no upsetting will occur in the ribs. This will prevent failure of the weld between the lug face and the draft sill web.

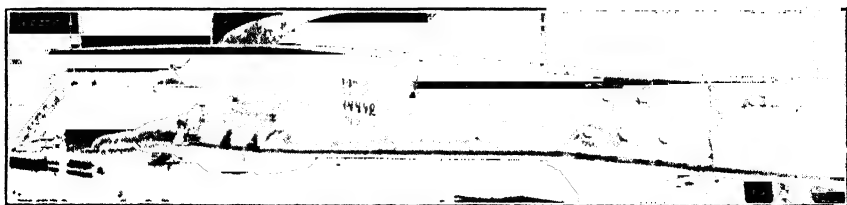



Fig. 4. Welded draft sill.

(c) Due to the fact that the load is applied on the draft lug face over an area whose center lies about one inch from the center of the web which must ultimately take this load, a horizontal rotating moment will be present. This moment must be resisted in part by the top plate of the draft sill, partly by the bottom flange and horizontal ribbing on the web, and partly by the draft gear carrier which is bolted to the bottom of the draft sill under the draft gear.

(d) It is important to investigate the "center end sill" to make sure that there is enough resistance at that point to develop 500,000 pounds and that the attachment of the buffer beam to the webs and top plate of the draft sill will transfer this force into the draft sill.

(e) The center end sill should be checked for strength to resist the force of 100,000 pounds upward at both points.

(f) The coupler carrier should be checked for a force of 100,000 pounds downward at any coupler position.

(g) The entire job should be calculated carefully to make sure that the small details are adequate and that the welds are properly specified.

Several "squeeze tests" have been made on welded cars having welded draft sills designed in this way. These tests were made at the Altoona

Shops of the Pennsylvania Railroad. During one of these tests, strain gauges were applied to the various parts of the car, particularly the draft sill. It was found that the stresses in the draft sill followed very closely the calculated stresses and that all stresses were well below the yield strength of the material. Furthermore, at least 1000 draft sills that were calculated in this way, have been constructed and not a single service failure has appeared. With one exception, all of the cars built since the design of this type of draft sill have used the welded type. It has been used on aluminum cars as well. This experience with welded draft sills proves beyond a doubt that, for equal weight, no other construction could be used to give greater safety or lower cost.

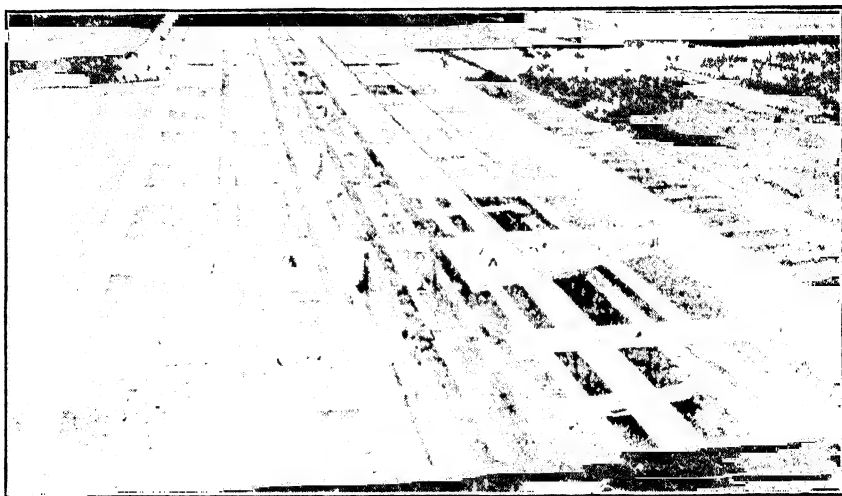



Fig. 5. Complete welded underframe.

Details of Construction—The all welded draft sill is principally of a box section comprising two vertical web members each 5/16-inch thick, a top plate 1/4-inch thick, and a bottom plate 1/2-inch thick. It is spliced to the centersill with a butt weld and reinforcing plates at top and bottom as shown just to the left of the bolster. The entire weight of the car body is carried to the truck at the center of the bolster where a "center filler" is used. The centersill is made by welding the toe of a rolled angle to the stem of a rolled tee to form a "J" section and it is supported on the load-carrying sides at approximately 8-foot 6-inch centers by the "crossbearers" which are welded I-sections built up from plate to form a tapered beam. Fig. 5 shows the complete welded underframe. The bolster is a double webbed welded member which carries the entire body weight to the center-filler. All cross members are welded to the side sill and centersill The centerfiller, which previously has been a casting, was plug-welded to the webs of the centersill.

A new welded centerfiller, (See Figs. 6 and 7), has lately been applied to one new passenger car for trial and after being proved successful, is to be incorporated in future cars as standard practice. The welded centerfiller saves a large percentage of weight since the cross ribs are welded directly

to the centersill, eliminating the entire side webs of the cast type. The "centerplate" which is the swivel bearing to the truck is riveted in place because it must be removed when wear takes place. The centerfiller and centerplate are interlocked as a safety measure in case the rivets are sheared by the force of 250,000 pounds referred to in item 5 under "A.A.R. Specifications".

The center lug which is a small steel casting must take most of the thrust from the coupler. It is cast with two legs which project through holes in the web of the sill to which they are welded. These legs are in turn welded to longitudinal ribbing which distribute the twisting moment described in item (c) under "Method of Calculating". Elimination of this casting and substitution with an arc welded steel lug is being considered at the present time because of the uncertainty connected with the use of a casting.

Directly below the draft lugs, the draft gear carrier is bolted to the bottom of the draft sill. This piece serves to support the draft gear and coupler tail knuckle (which must be removed periodically) but at the same time the carrier ties the lower flanges of the sill together to resist spreading, closing or twisting, in case of a severe blow on the coupler.

Before the end of 1939, steel castings were always used for the center filler, draft lug housings, and center end sills. The center end sill now used is entirely arc welded from plates and rolled channels. The vertical end posts are attached to the vertical portion of the end sill by welding through slots as well as by two fillet welds about two feet in length. The end posts are a rolled CB section, but, because the web of this section does not have sufficient area to meet the rules, the web is burned out and a thicker one welded in for a height of about three feet above the end sill.

Welding of Draft Sill—Fabrication of the welded draft sill is begun with sub-assembly of the web plates In this sub-assembly operation the draft lugs are located in the proper position on the web plates by means of a locating jig. The parts are tacked together in this jig, the size of the tacks being sufficient to hold the draft lug parts in their proper location after removal from the jig for welding. The plates are removed from the

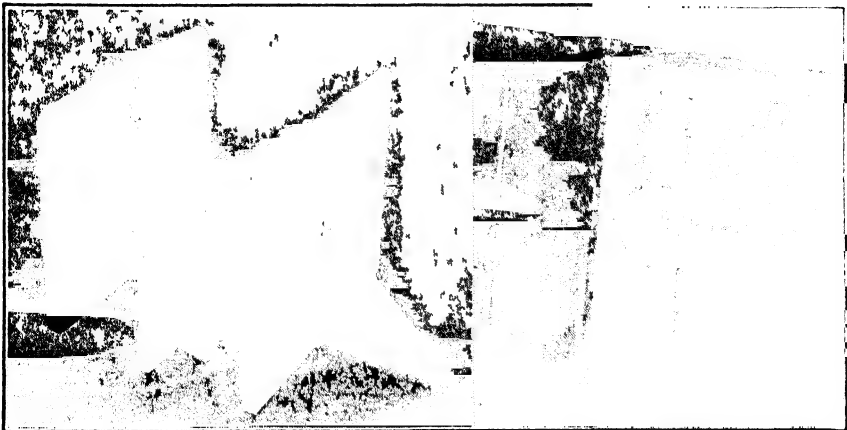



Fig. 6. (left). Sub-assembly of welded center filler. Fig. 7. (right). Welded center filler applied to draft sill.

jig for welding because the parts to be welded are then more accessible and the part is easily positioned manually by the welder for downhand welding.

The draft lugs transmit the entire buffing load of the draft gear into the draft sill and then to the center sill. This load is often suddenly applied and the lug attachment must withstand these impacts. The lugs are attached to the web with a double J-weld giving full penetration.

Upon completion of the draft lug welding, the web plates are assembled in a jig. The bottom flange plate, stiffener plates, and bolster center filler are added in this jig. All the parts are tack welded together and the assembly then taken out of the jig so that it can more easily be positioned for welding.

Positioning of the assembly is accomplished by attaching two circular rings. The draft sill is easily rolled on these rings to position the welding by the welder himself. When the welding is complete, the rings are removed and the top cover plate welded in place, after which the draft sill is attached to the center sill by means of a butt weld. The completed center sill is shown in Fig. 8.

Welding of End Sill—The center end sill, which was formerly part of the draft sill casting, and later a separate casting, is now made up entirely from plates and rolled structural members. Some of the plates are hot pressed to form parts of the end sill. These are first tacked together in assembly jigs and then positioned for final welding in special manipulators.

The structural channel members that stiffen the interior of the end sill are fillet welded to the bottom plate and plug welded to the top cover plate.

Positioning of the end sill, as with the draft sill, is best done with custom built positioners. The cost of these positioners is low and they serve very satisfactorily. The parts are turned manually and held in position by a pin acting in holes in a disc which is mounted on the supporting shaft.

Assembly Into Underframe—The draft sill and center end sill are not joined together until they are assembled in the underframe jig. The draft sill is first welded to the center sill. This center sill assembly is welded to the center end sill by means of butt welds.

Savings In Cost and Weight

	Draft Sills and End Sills	Draft Gear Carrier	Center Filler	Total
Cost of Casting	$1,524.80	$30.24	$56.58	$1,611.62
Cost of Weldment	792.02	23.14	14.66	829.82
Saving by Welding	732.78	7.10	41.92	781.80
% Cost Savings	48%	23%	74%	49%
Weight of Casting	6,395 lbs.	308 lbs.	560 lbs.	7,263 lbs.
Weight of Weldment	4,324 lbs.	286 lbs.	104 lbs.	4,714 lbs.
Saving by Welding	2,071 lbs.	22 lbs.	456 lbs.	2,549 lbs.
% Weight Savings	32%	7%	81%	35%

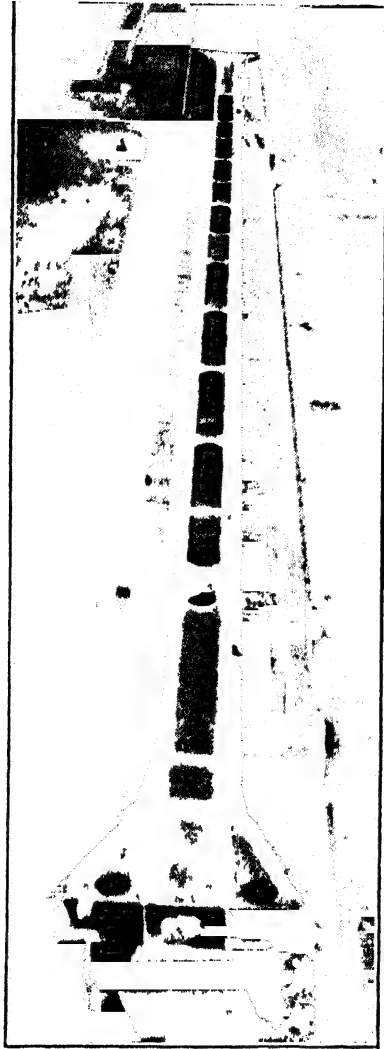



Fig. 8. Center sills and draft sills assembled.

During 1941, 228 cars were built in our shop. With a savings of $781.80 and weight reduction of 2,549 pounds per car from the use of the above welded parts, the yearly savings would be $178,250.40 and a savings of over 290 tons of steel.

There were 548 passenger cars constructed in the United States during 1941 for domestic use. If the welded draft sill parts had been substituted for castings on each of these cars, the cost difference would have been $428,426.40 and the weight difference would have been 700 tons.

Reductions in cost and weight of from one-third to one-half is the prime reason that continuance of the arc welding process is assured.

Chapter VII—Arc Welded Suspension for Air Conditioning System

By John F. Muller and Gonzalo C. Munoz,
Sales Engineer and Secretary-Treasurer, respectively,
The American Pulley Company, Philadelphia, Pa.

John F. Muller

Subject Matter: Study of the best method of suspending the compressor of a railroad car air-conditioning system. Cast iron was first considered and discarded because of the possibility of hidden defects and space limitations. Cast steel was prohibitive on account of its cost. Detailed accounts of the design of both arc welded and riveted compressor suspensions, together with a close stress analysis of the frame, are given. Elaborate weight and cost data on both systems indicate the advantages of arc welding, savings in amount of $17.11 per unit and hence, $51,330 per 3000 cars per annum being figured.

Gonzalo C. Munoz

Introduction—Any man of 60 can remember the old wooden railway passenger cars of his boyhood days, full of smoke and dust from the opened windows in summer, cold or overheated in winter; and lighted most inadequately from gas tanks under the car. They were not safe and they certainly were not comfortable.

In the early days of railroading, passenger trains ran only by day and did not require artificial lighting. As the railroad system was extended, night travel came into vogue, and the old stage-coach custom of the passengers bringing their own candles was extended to the passenger railway car. Later candles were provided by the railroads and protected by glass shields. In 1850 oil lamps were introduced and were later superseded by gas which was quite generally in use in the 1890's.

Experiments in electric lighting were first undertaken in the early 1880's and from this beginning countless electrical improvements have continued to the present time. The air brake was another important improvement which added immensely to the safety and comfort of passenger travel, as was the automatic coupler which supplanted the old inefficient link-and-pin, the cause of so many accidents among the train crew. In the early days, passenger cars were heated with stoves, and later by hot water heaters, until finally in 1903 the modern vapor heating was introduced. The first all-steel passenger coach was built in 1906, and today the old-fashioned wooden coach is seldom seen on our great trunk lines. The stream-lined train is a more recent development and the first successful one of this type was operated as recently as 1934.

Air conditioning of passenger cars began as "air cooling" in 1884, when the Baltimore and Ohio Railroad equipped a passenger car with an ice cooling system. In 1929, the same railroad successfully tested mechanical air conditioning in a passenger coach, and a year later put in operation the first mechanical air conditioned passenger train. From that date on progress

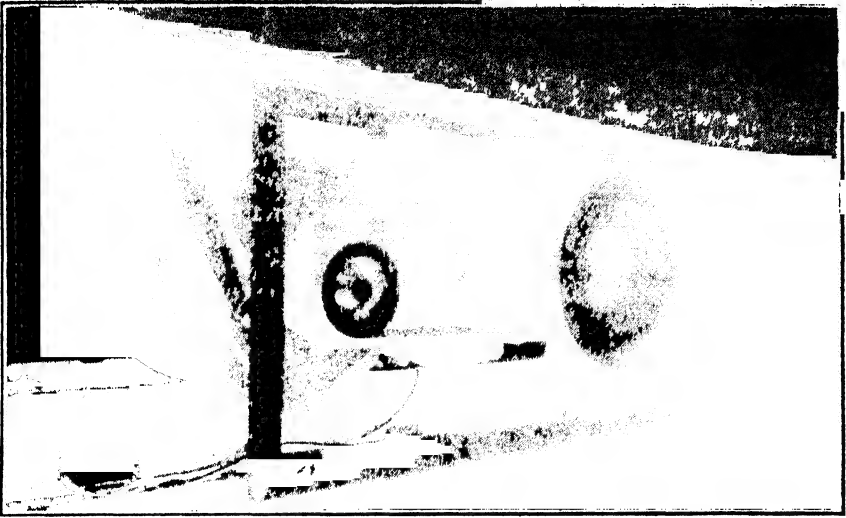



Fig. 1. Arc welded compressor suspension with compressor and motor in place.

throughout the country was rapid, and today there are approximately 12,800 air conditioned passenger cars in service in the country, and in which we can cross our western desert during a sand storm with the temperature at 115 degrees and sit in perfect comfort in a well-ventilated and air-conditioned car. We have come a long way since the early attempts at air cooling to the modern air conditioned car which filters the air, removes excess humidity, and cools it to a comfortable temperature

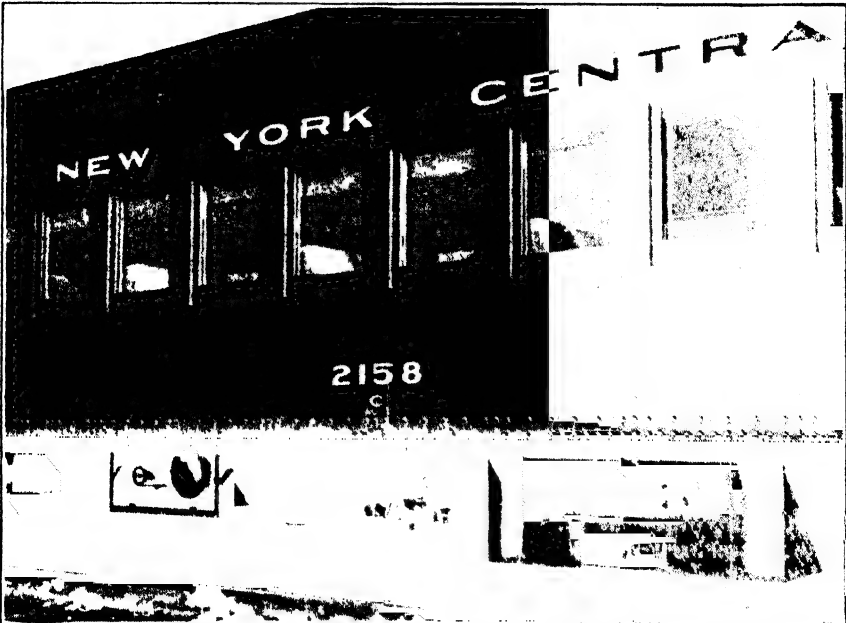



Fig. 2. Modern passenger car equipped with step-modulated air conditioning.

Step-Modulated Air Conditioning—The latest development in air-conditioning as applied to railway passenger cars is the "Lundy Continuous Control Air Conditioning System". It has recently been applied to twenty-five cars of one of our largest eastern trunk lines and fifty-five additional installations are now on order.

It is distinguished particularly by its use of a three-cylinder radial compressor which automatically operates on one, two or three cylinders, depending upon the demand for refrigeration. Complete on and off cycling is avoided and dehumidification is continuous. The evaporator is divided into two parts, a 45 per cent section operating at light loads, the full evaporator being in service when the cooling load is heavy. This causes the coils to operate always

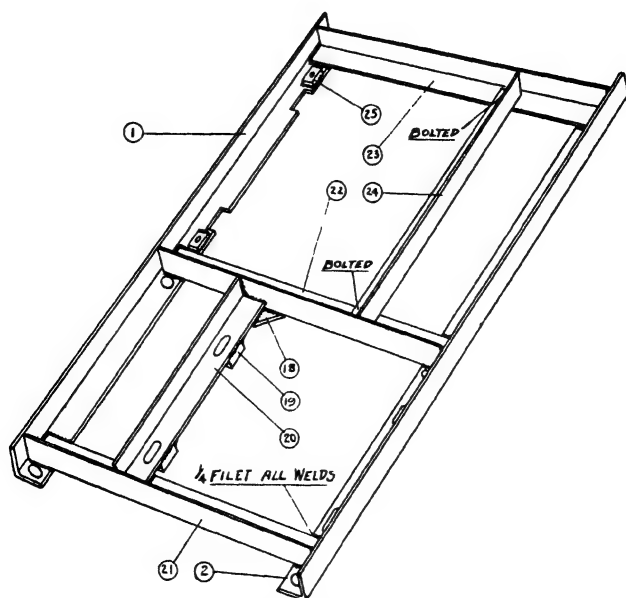
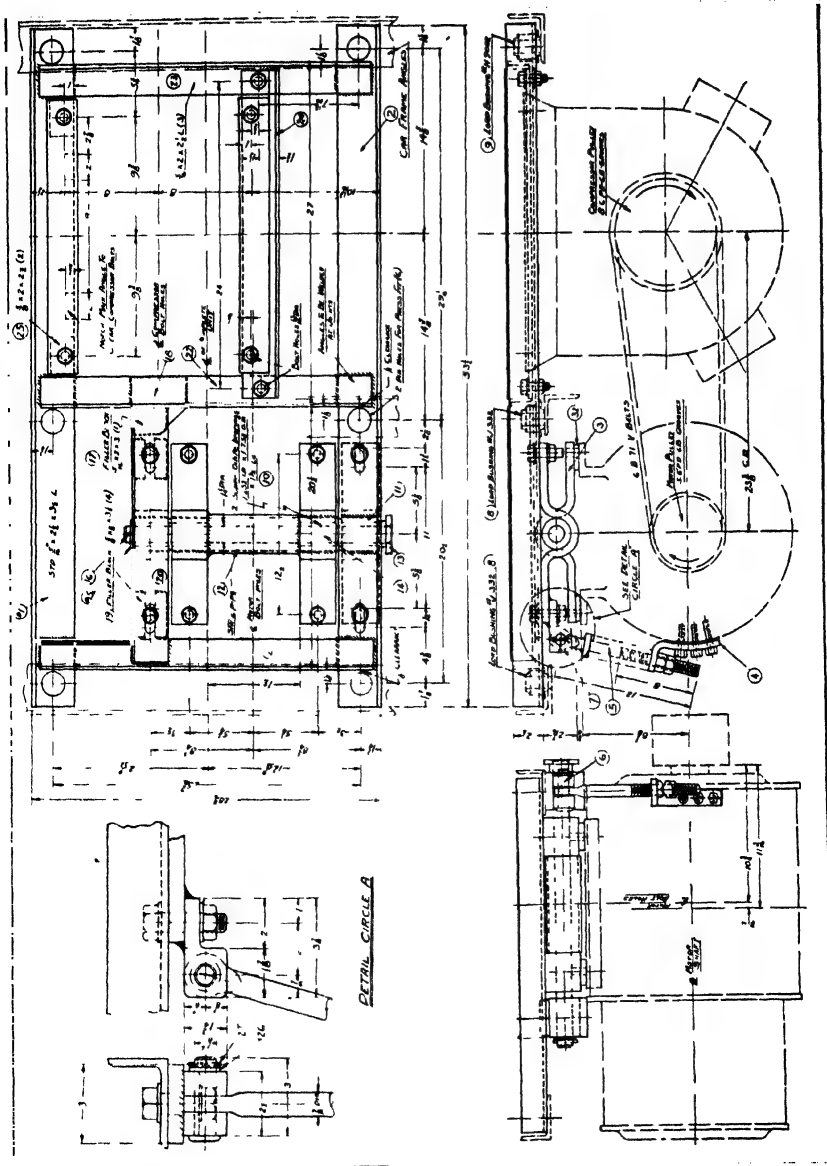



Fig. 3. Top view of upper frame.

at a low temperature, thus ensuring a constant removal of moisture from the air. The condensor and compressor are applied as separate units to ensure adequate cooling of each, and to facilitate their placement under the railway passenger car. The refrigerant used is "Freon". The compressor of this system is driven at a constant speed by a 10 horsepower 72 volts direct current motor, through a multiple V-belt drive.

A study of the best method of suspending this compressor and its motor resulted in the development of the arc welded compressor suspension for railway passenger cars, which is the subject of this thesis, illustrated in Figs. 1 and 2.

The Purpose of the Arc Welded Compressor Suspension—The purpose of the arc welded compressor suspension is to support the motor and compressor of the air conditioning unit under a railway passenger car frame, with provision for alignment of the motor pulley, for easy adjustment of belts to the proper tension, and for quick removal of the motor or the compressor for servicing.

Fig. 4. General assembly of arc welded compressor suspension.

Designs Considered—Four types of construction were considered for the design of the compressor suspension. Cast iron was discussed but eliminated as it was not acceptable to the railroad engineers, due to the danger of hidden defects and to the limited space available for the installation. Cast steel was acceptable but was found to be too expensive. Riveted structural sections and arc welded structural sections were considered, and cost estimates were made resulting in the selection of the arc welded design.

Description of the Arc Welded Compressor Suspension—The suspension consists of an arc welded monolithic angle iron upper frame, 28½ inches wide x 53½ inches long, as shown in detail in Fig. 3, which is bolted to the under-structure of the railway passenger car. Due to the fact that the railroad engineers were very emphatic in their desire to have all connections of a positive nature, the frame was designed to rest on top of and be bolted to the under-structure of the railway passenger car with ⅞-inch bolts, as in Fig. 4, which shows the three angles of the car under-structure in dotted lines.

One of the interior angles of the frame, Part No. 24, shown on Fig. 3, is bolted to the monolithic frame in order to more readily remove or replace the compressor, the feet of which rest on the upper side of angle irons, Parts Nos. 1 and 24, thus providing ready removal or replacement of this unit for purposes of servicing.

The 10-horsepower motor driving the compressor through a multiple V-belt drive is suspended on a pivoted base which is supported on the horizontal legs of angle irons, Parts Nos. 2 and 20, (See Fig. 4). This pivoted base consists of four motor arms, Parts Nos. 3, (See Fig. 4), the outer two of which are bolted to the frame, described immediately above, and have bushed bearings, Parts Nos. 10 and 11, welded to the inside of their semi-circular formed sections, (See Fig. 5). A piece of 1¼-inch diameter case-hardened cold rolled steel, supported by these two bearings, acts as the pivot for the motor. The two interior motor arms, parts marked No. 3, rest on the pivot rod through similar bearings and form the supports for the four legs of the motor.

The motor arm, Part No. 3, nearest the outer edge of the passenger car has welded to one end a tension rod pivot block, Part No. 7, to which is attached the adjustable tension rod, Part No. 5. The threaded lower end of this rod passes through a hole in the motor clip, Part No. 4. An examination of this part on Fig. 4, shows that by tightening this bolt the motor is caused to rotate around the pivot increasing the center distance between the motor pulley and the driven pulley on the compressor thereby tightening the belt. It is obvious therefore that through this device a service man may adjust the

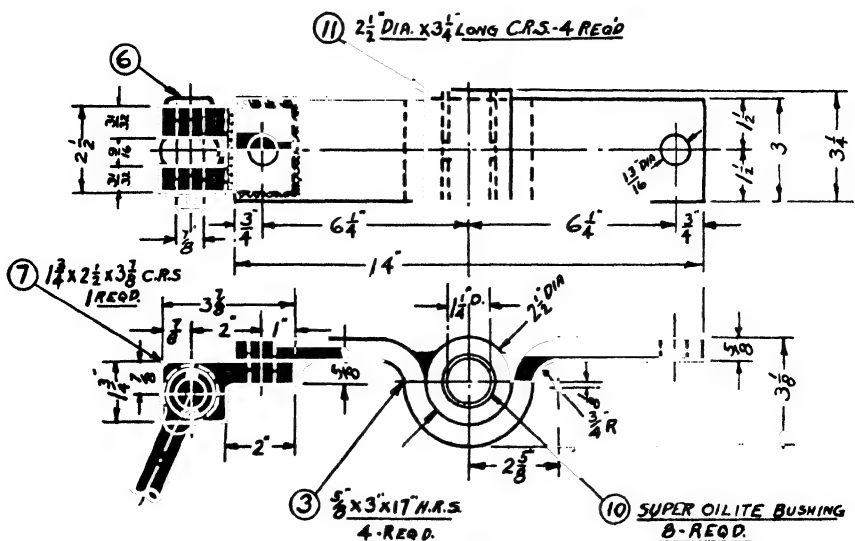



Fig. 5. Pivoted motor arm.

belt on this drive to the proper tension in a matter of a few seconds while the railway passenger car is stopped at a station.

The motor may be quickly removed for servicing by withdrawing the motor support pivot rod cotter pin, Part No. 16; withdrawing the motor support pivot rod, Part No. 14; lowering the motor (to which two of the motor arms are attached) on to a dolly previously placed underneath; and removing the motor to the repair shop. The serviced or new motor may be replaced by carrying out the above operations in reverse order.

The three cross angle irons, Parts Nos. 21, 22 and 23, of the upper frame are designed to rest on the horizontal legs of the longitudinal angles, Parts Nos. 1 and 2, and be securely arc welded together to meet the requirements of positive connections insisted on by the railroad engineers. The six 7/8-inch bolts fastening the upper frame of the suspension to the underframe of the passenger car pass through tubular rubber mountings. The function of these mountings is to absorb the tremendous shock existing in all railroad rolling equipment, and also to prevent vibrations caused by the operation of the compressor from being carried into the body of the railway passenger car. Fig. 4 shows slotted holes in Parts Nos. 2 and 20. These are for the four bolts fastening the motor arms, Parts Nos. 3, to the upper frame, and provide adjustment for belt alignment between the motor and the compressor.

Table I gives a complete parts list of the arc welded design.

TABLE I—PARTS LIST, ARC WELDED DESIGN

Part No.	Description	Number Required
1	Main Frame Angle (Compressor side)	1
2	Main Frame Angle (Motor support side)	1
3	Motor Arms	4
4	Motor Clip	1
5	Adjustable Tension Rod	1
6	Tension Rod Pivot Pin	1
7	Tension Rod Pivot Block	1
8	Lord Bushing #J-332	4
9	Lord Bushing #H-9002	2
10	Super-Oilite Bearings #S-1701-S	8
11	Bearing Retainer 2½" diameter x 3½" long C.R.S.	4
12	2" Pipe Spacer	1
13	Motor Support Pivot Rod End Cap	1
14	Motor Support Pivot Rod	1
15	Motor Support Pivot Rod Washer	1
16	Motor Support Pivot Rod Cotter Pin	1
17	Filler Block 5/16" x 2" x 3" H.R.S.	1
18	Gusset Plate	1
19	Motor Arm Spacer Blocks 5/8" x 7/8" x 3½" H.R.S.	4
20	Intermediate Angle, Motor Arm Support	1
21	Motor End Cross Angle 5/16" x 2" x 2½" x 27¼" angle	1
22	Intermediate Cross Angle 5/16" x 2" x 2½" x 27¼" angle	1
23	Compressor End Cross Angle 5/16" x 2" x 2½" x 27¼" angle	1
24	Intermediate Compressor Angle 5/16" x 2" x 3" x 25¾" angle	1
25	Compressor Spacer Blocks 5/8" x 2" x 2½" H.R.S.	2
26	Tension Rod Pivot Pin Washer	1
27	Tension Rod Pivot Pin Cotter Pin	1
28	¾" x 2" bolts and nuts with lock washers	2
29	¾" x 3½" Hi-Tensile bolts and nuts	8
30	7/8" Tension rod nuts	3
31	7/8" x 4" Frame bolts and nuts	6
32	¾" x 2" x 2" Spacer Blocks H.R.S.	4
33	7/8" x 2" x 2" tapered washers, malleable iron	4
34	¾" x 2½" bolts and nuts with lock washers	4

Description of Riveted Compressor Suspension—In all essential functions the riveted design, is similar to the arc welded design. All connections between members of the upper frame are riveted with the exception of Part No. 24 which is bolted to the main frame. The principal weakness of this riveted design is the loss of the monolithic construction obtained through arc welding.

The three motor arms, Parts No. 3, and the tension rod pivot block, Part No. 7, are machined to shape from a solid block of steel and are bolted securely to either the upper frame or the motor feet. The connections to the underframe of the railway passenger car are similar to the connections described under the arc welded design.

Table II gives a complete parts list of the riveted compressor suspension.

TABLE II—PARTS LIST, RIVETED DESIGN

Part No.	Description	Number Required
1	Main Frame Angle (Compressor side)	1
2	Main Frame Angle (Motor Support side)	1
3	Motor Arms	3
4	Motor Clip	1
5	Adj. Tension Rod	1
6	Tension Rod Pivot Pin	1
7	Tension Rod Pivot Block	1
8	Lord Bushing #J-332	4
9	Lord Bushing #H-9002	2
10	Super Oilite Bearings #S-1701-S	8
11	Not used (Part of No 3)	
12	2" Pipe Spacer	1
13	Not used (Part of No. 14)	
14	Motor Support Pivot Rod and Cap	1
15	Motor Support Pivot Rod Washer	1
16	Motor Support Pivot Rod Cotter Pin	1
17	Intermediate Support Angle	1
18	Gusset Plate	1
19	Not used (Part of No. 20)	
20	Intermediate Motor Support	1
21	Motor End Cross Angle 5/16" x 2" x 2½" x 27¼"	1
22	Intermediate Cross Angle 5/16" x 2" x 2½" x 27¼"	1
23	Compressor End Cross Angle 5/16" x 2" x 2½" x 27¼"	1
24	Intermediate Compressor Angle 5/16" x 2" x 3" x 25¾"	1
25	Compressor Spacer Blocks ⅝" x 2" x 2½"	2
26	Tension Rod Pivot Pin Washer	1
27	Tension Rod Pivot Pin Cotter Pin	1
28	¾" x 2" bolts, nuts and lock washers	2
29	¾" x 3½" Hi-Tensile bolts and nuts	8
30	⅞" Tension rod nuts	3
31	⅞" x 4" Frame bolts and nuts	6
32	¾" x 2" x 2" Spacer blocks	4
33	⅞" x 2" x 2" Tapered Washer	4
34	¾" x 2½" Bolts and Nuts	4
35	½" x 1" Button head rivets	38

Determination of Stresses in the Arc Welded Compressor Suspension—Railroad engineers are extremely cautious in the design of every detail connected with a railway passenger car. It was therefore necessary to study every feature of the design of the compressor suspension, due to the fact that a failure in one of its members, or in the connection between the suspension and the equipment fastened thereto might result in a serious railroad accident. Liberal factors of safety were used throughout.

The following stress calculations were made to ensure that all members

and all connections had ample factors of safety to withstand the loads that they are intended to carry while in operation:

(a) One member in which the stresses must be considered is the intermediate cross angle piece No. 22. The deflection of this member is determined by considering it as a beam fixed at both ends with concentrated load not at the center.

The origin of coordinates is taken at Point Y. The moment at any point on the left portion of the beam is —

$$Ma = \frac{Pbx}{L}$$

and that at any point on the right portion is

$$Mb = \frac{Pbx}{L} - P(x - a)$$

For the left portion of the beam—

$$\frac{EI}{P}\frac{d^2y}{dx^2} = \frac{bx}{L}$$

$$\frac{EI}{P}\frac{dy}{dx} = \frac{bx^2}{2L} + C$$

$$\frac{EI}{P}y = \frac{bx^3}{6L} + C_1 X - C_3$$

For the right portion of the beam—

$$\frac{EI}{P}\frac{d^2y}{dx^2} = \frac{bx}{L} - (x - a)$$

$$\frac{EI}{P}\frac{dy}{dx} = \frac{bx^2}{2L} - \frac{(x-a)^2}{2} - C_2$$

$$\frac{EI}{P}y = \frac{bx^3}{6L} - \frac{(x-a)^3}{6} - C_1 X + C_4$$

At the left end $y = O$, $X = O$, therefore $C_3 = O$.
The deflection under load for both portions is the same,

$$\frac{ba^3}{6L} + C_1 a = \frac{ba^3}{6L} - \frac{(a-a)^2}{6} - c_1 a + C_4$$

$$C_4 = O$$

For the right portion of the beam y O where X - - L

$$O = \frac{6L^2}{6} - \frac{b^3}{6} + C_1 L$$

$$C_1 = \frac{b^3}{6L} - \frac{bL}{6}$$

The equation for the elastic curve for the left portion is,

$$\frac{EI}{P}y = \frac{bx^3}{6L} - \frac{bLx}{6} + \frac{b^3X}{6L}$$

and if $X = A$

$$Yp = \frac{Pa^2 b^2}{3EIL}$$

The slope equation for the left portion of the beam becomes,

$$\frac{EI}{P}\frac{dy}{dx} = \frac{bx^2}{2L} + \frac{b^3}{6L} - \frac{6L}{6}$$

Since the slope equals zero at the point which has a maximum deflection:

$$O = \frac{bx^2}{2L} + \frac{b^3}{6L} - \frac{bL}{6}$$

$$\text{Then } X = \sqrt{\frac{L^2 - b^3}{3}}$$

(X varies from 0.5L to 0.577L as b varies from $\frac{L}{2}$ to zero).

Use this value of X in the equation for the elastic curve and the maximum deflection Y is:

$$\text{Maximum } Y = \frac{-Pb}{27EI}(L^2 - b^2)\sqrt{3(L^2 - b^2)}$$

Deflection at the middle is given by:

$$Yc = -\frac{Pb}{EI}\left(\frac{L^2}{16} - \frac{b^2}{12}\right)$$

Y = Deflection in inches
P = 850 lbs. (½ wt. of motor + ½ wt. of compressor)
b = $5\frac{11}{16}''$
A = $17\frac{1}{2}''$
E = 30,000,000 lbs./sq. in.
I = .45
L = $23\frac{3}{16}''$

$$Y = -\frac{850 \times 5.682}{30{,}000{,}000 \times .45}\left(\frac{23.183^2}{16} - \frac{5.682^2}{12}\right)$$

$$Y = -.0141'' \text{ (deflection)}$$

The maximum span = 360 × deflection:

$$\frac{\text{Max. span}}{360} = \text{deflection}$$

$$\frac{23.183}{360} = \text{deflection} = .0638''$$

Therefore the $\frac{5}{16}$x2x2½" angle will withstand a safe load of

$$\frac{.0638}{.0141} \times 850 = 3845 \text{ lbs.}$$

This gives a factor of 4.52 over the maximum allowable deflection for the span in question.

(b) The joining of Part No. 20 to Part No. 22 is made by a butt weld, further strengthened by means of gusset plate No. 18. One quarter inch fillet welds are used on all joints, welds being made with ¼" diameter electrode, using a 300-ampere arc welder.

(c) Welding of tension rod pivot blocks to motor arm.

The forces to be considered at this point are:

W = Motor weight — 650 lbs.
W_1 = Motor pulley weight — 50 lbs.
T_1 = Tight side belt tension.
T_2 = Slack side belt tension.
P = Tension in adjustable tension rod.

Taking Moments about Motor Base Pivot:

(1) $P \times 8'' + M \times O = T_T \times 10\frac{3}{4}''$

Determine T_T as follows:

(2) Belt speed = $.262 \times 5.6 \times 1760$ R.P.M. = 2580 ft. per min.

(3) $E_T = T_1 - T_2 = \dfrac{33{,}000 \times 10 \text{ H.P.}}{2580 \text{ ft./min.}} = 128$ lbs.

Where E_T = effective tension

(4) $\dfrac{T_1}{T_2} = 4.0$ for V belt

$T_1 = 4T_2$

Substitute in (3)

$T_1 - T_2 = 4T_2 - T_2 - 3T_2 = 128$ lbs.

$T_2 = \dfrac{128}{3} = 42.7$ lbs.

$T_1 = 4T_2 = 4 \times 42.7 = 170.8$ lbs.

(5) $T_1 + T_2$ = Total tension T_T = 170.8 lbs. + 42.7 lbs. = 213.5 lbs.

Substitute in (1)

$P \times 8 - M \times O = T_T \times 10\frac{3}{4} = 213.5 \times 10\frac{3}{4} = 2295$ in lbs.

$P = \dfrac{2295}{8} = 287$ lbs.

The tension rod pivot block is $2\frac{1}{2}$ inches wide and is to be welded to the motor arm by $\frac{1}{4}$-inch fillet weld by the shielded arc process. One half-inch of this will be required for starting the weld, leaving a length of 2 inches of weld at top and bottom, or a total of 4 inches.

One lineal inch of $\frac{1}{4}$-inch fillet weld by shielded arc process has a safe allowable stress of 2500 pounds in shear.

Using a factor of safety of 10 due to vibration and shock set up in railway car equipment, each lineal inch would then have a safe allowable stress of 250 pounds.

4 inches of $\frac{1}{4}$-inch fillet weld = 4 x 250 or 1000 pounds.

The tension on the weld figured in (5) above is 287 pounds, thereby giving an additional factor of 1000/287 or 3.5.

(d) Welding of cross angles to main angles at the compressor end of the suspension.

Two forces must be considered in the members at the compressor end, the weight of the compressor, which is 900 pounds, plus its flywheel weighing 100 pounds, and the pull of the belt which is figured above in (5) as 287 pounds. The former force acts vertically downward, while the latter acts horizontally.

The four corners must resist turning moments equivalent to 22 inches $\times$ 287 pounds = 6314 inch pounds and also hold the compressor weight of 1000 pounds or $\dfrac{1000}{4} = 250$ pounds per joint.

Length of $\frac{1}{4}$-inch fillet weld required:

$$S \times 10.5 = \frac{6314}{4}$$

$$S = \frac{6314}{42.0} = 150 \text{ lbs.} \times 10 \text{ (shock factor)} = 1500 \text{ lbs.}$$

One lineal inch of ¼″ fillet weld = 2500 lbs.

$$\frac{1500}{2500} = .6 \text{ inches of weld per joint.}$$

Using a rigidity factor of 5

$$5 \times .6 = 3.0'' \text{ of weld required per joint.}$$

In making the welds at these joints ¼-inch electrode were used with a current of 190 amperes, a voltage of 30, a welding speed of 30 feet per hour, and it is estimated that .2-pound of electrode were used per foot. Only one pass was required for each fillet, all welds being made in the flat position.

(E) Strength of motor and compressor bolts

Bolts used are parts No. 29 — ¾x3″ high tensile bolts — 110,000 lbs. per square inch. Area at root of threads = .311 square inch.

1 bolt = .311 × 110,000 lbs./sq. in. = 34,210 lbs.

Max. load per bolt = 150 lbs. in shear + 250 lbs. in tension (from above).

Max. load per bolt = $\sqrt{(150 \text{ lbs.})^2 + (250 \text{ lbs.})^2}$ — 291 lbs.

Factor of safety per bolt = $\frac{34{,}210}{291}$ = 117 which factor is far in excess of the shock safety factor required for safe railroad operation.

The tensile strength and bolt dimensions were specified by the railroad engineers.

Cost Estimate of Arc Welded Design Compressor Suspension—The initial order for these units was for a trial Step-Modulated air conditioning installation on twenty-five passenger cars, and therefore our preliminary estimate is based on this small number (25 units). There is shown in Table III a cost estimate of the complete assembled arc welded unit:

TABLE III—COST PER UNIT, ARC WELDED DESIGN, 25 UNITS

Total Shop Cost 25 Arc Welded Units	$1161.73
Shop Cost per Arc Welded Compressor Suspension When Made in Quantity of 25	46.47
Gross Weight of Material in 25 Arc Welded Units	4900 lbs.
Gross Weight of Material per Arc Welded Unit when made in Quantities of 25	196 lbs

Through correspondence with the Association of American Railways, Washington, D. C., it has been ascertained that there are today approximately 47,000 railway passenger cars, including Pullman cars, in the United States, and approximately 6000 in Canada, making a total in the two countries of approximately 53,000. As all of these cars with the exception of the 87 cars now being equipped with step-modulated air conditioning are potential users of this improved system, and as inquiries as high as the equipment for 400 cars for one customer have recently been under discussion, it appears that within the near future it will be possible to manufacture these units in lots of 1000. It also appears to be conservative accounting to amortize the cost of the special dies, jigs and fixtures over a lot of 3000 units. For the above reasons the cost estimate of the arc welded compressor suspension manufactured in quantity lots is based on lots of 1000, and the amortization of the tools, jigs and fixtures over a total of 3000 units.

Table IV gives cost per unit based on 1000 units.

TABLE IV—COST PER UNIT, ARC WELDED DESIGN, 1000 UNITS	
Total estimated shop cost 1000 arc welded units	$27,897.65
Shop cost per arc welded compressor suspension when made in quantities of 1000	27.90
Gross weight of materials 1000 arc welded units	184,600 lbs.
Gross weight of materials per arc welded unit when made in quantities of 1000	184.6 lbs.

Cost Estimate of Riveted Compressor Suspension:—There is shown in Table V the cost of the complete assembled riveted unit.

TABLE V—COST PER UNIT, RIVETED DESIGN, 25 UNITS	
Total estimated shop cost of 25 riveted units	$1,801.00
Estimated shop cost per riveted unit when made in quantities of 25	72.04
Gross weight of material in 25 riveted units	8,455 lbs.
Gross weight of material per riveted unit when made in quantities of 25	338 lbs.

Table VI gives cost per unit based on 1000 units.

TABLE VI—COST PER UNIT, RIVETED DESIGN, 1000 UNITS	
Total estimated shop cost, 1000 riveted units	$45,013.03
Shop cost per riveted compressor suspension when made in quantities of 1000	45.01
Gross weight of material in 1000 riveted units	248,200 lbs.
Gross weight of material per riveted unit when made in quantities of 1000	248.2 lbs.

Proportionate Cost Saving of Arc Welded Design—A study of the cost estimates of the arc welded construction as compared with the riveted construction shown in the Tables results in the following comparisons:

Manufactured in Lots of 25 Units	
Shop cost of Riveted Unit	$72.04
Shop cost of Arc Welded Unit	$46.47
Estimated saving per unit of arc welded construction compared with riveted construction	$25.57
Proportionate cost saving of arc welded construction (in percentage) over cost of riveted construction	35.4%

Manufactured in Lots of 1000 Units	
Shop cost of Riveted Unit	$45.01
Shop cost of Arc Welded Unit	$27.90
Estimated saving per unit of arc welded construction compared with riveted construction	$17.11
Proportionate cost saving of arc welded construction (in percentage) over cost of riveted construction	37.9%

As explained in detail under the heading "Cost Estimate of Arc Welded Design Compressor Suspension" we expect that future runs in the manufacture of this product will be in quantities of 1000 units and therefore the proportionate cost saving of 37.9 per cent resulting from the arc welded construction over the cost of riveted construction is the figure which will obtain in future manufacturing.

Estimated Total Annual Gross Cost Savings Accruing from the Use of the Arc Welded Design—The great industrial development which followed the first World War resulted in the early years in the development of the railroad passenger business to its peak, at which time there were approximately 55,000 passenger cars, exclusive of Pullman cars in the United States. From that point on, the rapid development of the automobile industry resulted in a decline in the number of passenger railway cars, down to the present figure of approximately 39,000, exclusive of Pullman cars. The railroads have now found a shortage of passenger cars, and have commenced a construction program, and it is estimated that within the next few years we should reach a total of 44,000 cars. By adding the 8000 Pullman cars in the United States, and the 6000 passenger cars in Canada, it will raise the total in the near future to 58,000 cars, of which only 87 are equipped with step-modulated air conditioning, and 12,887 with one of many types of air conditioning. Deducting these air conditioned cars from the estimated future total leaves 45,113 cars which will doubtless be air-conditioned within the next few years.

During the present war crisis, air conditioning of passenger cars must be postponed temporarily, but it will be a useful and desirable improvement during the immediate post-war years when capital expenditures will be sought to take up the slack during the shift from a war to a peace time economy.

It is assumed in these estimates that after the close of the war, the remaining passenger cars in the country will all be air conditioned over a period of five years, which will require the air conditioning of 9000 cars per year, and it is further assumed that one-third of the necessary compressor suspensions for these air conditioning installations will be built by the company with which the authors are connected, and two-thirds will be built by other concerns.

Based on the above estimates the total annual gross cost savings accruing from the use of arc welding by the company with which the authors are connected are estimated to be:

Compressor Suspensions for 3000 Cars

Estimated proportionate saving per unit of arc welded construction,	$17.11 each
3000 cars per year	
Total estimated annual gross cost saving accruing from use of arc welding	$51,330.00

Estimated Total Annual Gross Cost Saving Accruing from the Use of Arc Welding by Industry in General—Based on the assumptions outlined immediately above, the estimated total annual gross cost saving accruing from the use of arc welding by industry in general can be determined by estimating that 9000 cars will be air conditioned per year, and that the saving per unit by the use of arc welding is $17.11; resulting in a total annual gross cost saving of $153,990.

Due to the world war crisis of today it is impossible to obtain reliable figures regarding railroad equipment for countries other than the United States and Canada, and although the authors recognize that there will eventually be great possibilities for air conditioning installations in railroad passenger cars all over the world, the estimates in this thesis are based solely on the total annual gross cost savings accruing from the use of arc welding by industry in general in the United States and Canada.

Increased Service Life Accruing from the Use of Arc Welding—The conditions to be met in the design of the compressor suspension were vibration and shock loads, both of which are present on railroad rolling equipment. Severe shock and vibration tend to loosen rivets, and thereby shorten the service life of a riveted compressor suspension.

It is the belief of the authors of this paper that the monolithic construction of the arc welded compressor suspension will cause it to last almost indefinitely if kept properly painted. The wearing surfaces of the pivot and the tubular rubber mountings of the bolts will have to be repaired or renewed at infrequent intervals but the arc welded frame will last as long as the passenger car. The authors have had experience with riveted equipment used in connection with drop hammers, rock crushers and other installations where loads were intermittent, and vibration severe, causing riveted joints to become loose in a few weeks. They found it was possible to correct these difficulties by arc welding.

Increased Efficiency Accruing from Use of Arc Welding—The summary estimate demonstrates that the efficiency in the manufacture of the arc welded design as compared with the riveted design results in an annual gross cost saving of $17.11 per unit or $153,990 per year.

The cost estimates of the arc welded design, as compared with the riveted design, show that there is a saving of approximately 6.6 man hours per unit, or 59,400 man hours per year by the use of arc welding. (Based on a saving of $5.28 in labor per unit @ 80 cents per hour.)

Owing to the simplicity of the arc welded design as compared with the riveted design there is eliminated approximately 5.8 machine hours per unit, or 52,200 machine hours per year, leaving this machine time available for other work which cannot be so readily replaced by arc welding.

Increased Social Advantages Accruing from the Use of Arc Welding—Economists the world over have for many years emphasized the importance to all industrial countries of the conservation of its raw materials. The arc welded design of the compressor suspension is not only stronger than the riveted design, but it also results in a saving of one-hundred pounds of steel per suspension. Based on the equipment of 9000 cars per year, this will result in the conservation of 900,000 pounds of steel per year.

Safety to passengers has for many years been the governing consideration in all railroad design and construction. The arc welded compressor suspension, free of rivets which might shake loose under the shocks and strains of service, is considered safer than the riveted design.

Some of the advantages of arc welding compared with riveting are:

1. The formation of a monolithic unit with the resulting greater rigidity and strength.
2. The elimination of the expense of rivets, rivet holes and riveting.
3. Elimination of the weakening of structural members caused by rivet or bolt holes.
4. Reduction in the weight of most structures.
5. Improved appearance.
6. Reduction in cost of manufacture (in most instances).

The relatively low cost of steel and its high tensile strength, coupled with the great compressive strength of modern structural sections, of which the angle, the channel and the I-beam are the best examples, are the main reasons why the present era is known as the "steel age".

The individual pieces of steel such as channels or I-beams are in themselves of little or no practical value, but when skillfully used as units of a completed

design the great modern bridges, buildings and other engineering structures are created to carry the commerce and house the industry of our civilization.

One of the most difficult problems in the design of steel structures is the connection of the various members one to the other, in such a manner as to develop the full strength of each. Riveting and bolting the members together has until quite recently been the standard, and in fact the only method employed in the design of steel structures, until various types of welding were perfected shortly after the first World War. Electric arc welding is the leader in this new art, and today we see the arc welded ships, tanks, building frames, and countless other engineering structures replacing their riveted predecessors.

Chapter VIII—Construction of Rail Grinding Car

By J. C. Bowles,

Superintendent of Equipment, The Community Traction Co., Toledo, O.

J. C. Bowles

Subject Matter: Passing through a period of replacing street cars with motor coaches and trackless trolleys, this company was the recipient of complaints of the noisy operation of those cars still in service, as a result of rail and wheel wear. The market price of rail grinding equipment being $40,000, this company, with the aid of the arc welder, mounted rail grinding equipment in an existing car and saved themselves over $10,000. Further, some $4,000 annually is saved as compared with the operation of their portable grinding equipment. Complaints from riders and residents in the vicinity of the line, decreased on the average, by 86%.

During the past several years, our company, along with others of the transit industry, has undergone a period of transition, that of replacement of street car equipment with motor coaches and trackless trolley coaches.

The design of coaches during this period has advanced from front engine, city type, to the rear engine, streamlined transit type vehicle, with all the features of attractiveness and comfort that are desirable on a modern public carrier. The coaches are more flexible in operation, they operate faster schedule speeds, and are considerably less noisy than the cars which they replaced.

The comparatively few cars which are still in service have become a source of noise complaints from residents along the line as well as riders themselves. Even though the cars have been properly maintained, painted streamline, and lighted adequate for reading, the noise from the steel wheels on the rail remains the same.

The problem of satisfying those complainants merely meant the reduction of noise by more frequent grinding of car wheels and rails. However, our problem was one of additional rail grinding equipment for this purpose. The desirable equipment was on the market at approximately $15,000 for the rail grinder and an additional $25,000 for a car, making a total of $40,000. With our operation of less than 100,000 car miles per month, we began our thinking to develop a more economic means of grinding rail.

It was in this line of thought that arc welding appeared as a possible prime factor, as it had on many previous occasions, for construction or reconstruction of equipment in our shops. The idea of rebuilding an obsolete wrecker rail car into a reciprocating rail grinder car at a minimum cost involved considerable arc welding.

The construction was undertaken and completed in a period of seven weeks at a total cost for labor and material of $4,400. Of this expenditure, $4,120 was for construction and installation of the rail grinder, while the balance of $280 was used for reconditioning, lighting, and replacing of motor field coils such that the car could operate at very slow speeds. Since

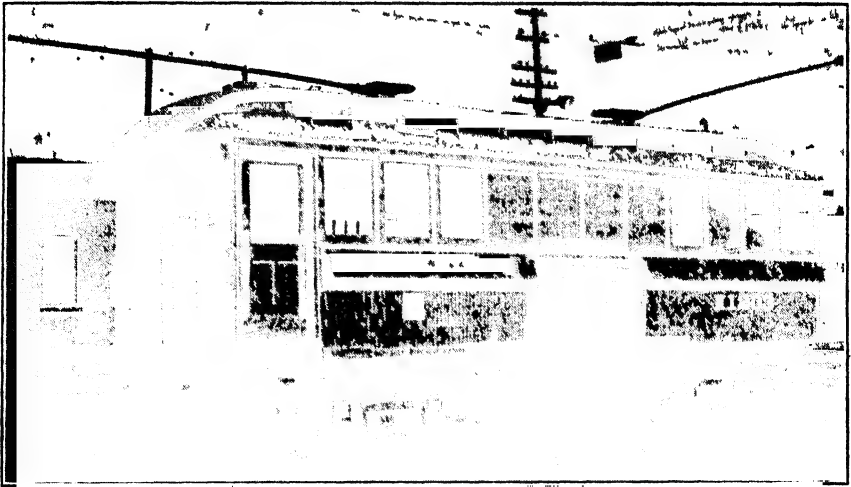



Fig. 1. The subject of study.

we had the car, we calculate our saving only on the rail grinding equipment. This saving, based on our construction cost of $4,120 as compared to the purchase of new equipment at $15,000, was $10,880 or 72.8 per cent of the cost of new equipment.

Arc welding was used throughout the rebuilding process for the following numerous purposes making use of four types of welding rod:

1. Reinforcement of the framework of the car.
2. Construction of two sets of framework for support and mounting of motors and grinding units. This was made of 3-inch pipe standards, 5-foot 2-inch channel iron cross members, and had brackets for bracing and attachment to the car frame.
3. Construction of a housing to enclose the grinding brick boxes.
4. Slide plates welded to the brick boxes
5. Brick boxes to accommodate four 2-inch x 4-inch x 8-inch bricks, each in a separate compartment, were made by arc welding

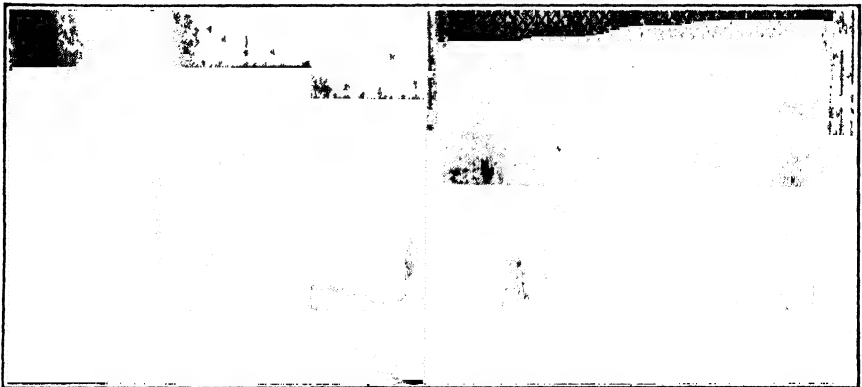



Fig. 2. (Left.) Rail grinder mechanism. Fig. 3. (Right.) Another view of rail grinder mechanism.

6. Mounting brackets for air cylinder controlling pressure on grinding brick and on wedge block.
7. Crankshaft made of 3-inch nickel steel shafting welded onto hot rolled plates.
8. Turnbuckle eyes for motor adjustment.
9. Slides for raising and lowering grinder units These were made from 3½-inch pipe and 6-inch channel iron.
10. Rail guide shoes, made from a section of street car wheel welded to 1½-inch square steel.
11. Facing of rail guide shoe wearing surface with tool weld.
12. Brackets, braces, and platform for motor mounting.
13. Making T irons for lifting grinder units with 8-inch air cylinder.
14. Attachment of fittings to cooling water supply tanks

Photographs, Figs. 1, 2, 3 and 4 show the car and the rail grinder mechanism.

Reference to the above items is made on Fig 5 by encircling the item number, thus indicating where the welding was done.

The rail grinder when completed was equipped to grind two rails at the same time as the car moved along at any desired speed between the limits of standstill and 60 feet per minute The reciprocating mechanism operated by electric motors allowed for the control of reciprocation speeds as desired—depending on the condition of the rail, the control of mechanism for each grinder being independent of the other. The pressure of the grinding stone on the rail is controlled by air pressure. The rail guide shoes ride the car rail during grinding to keep the proper alignment of the grinding brick on the rails

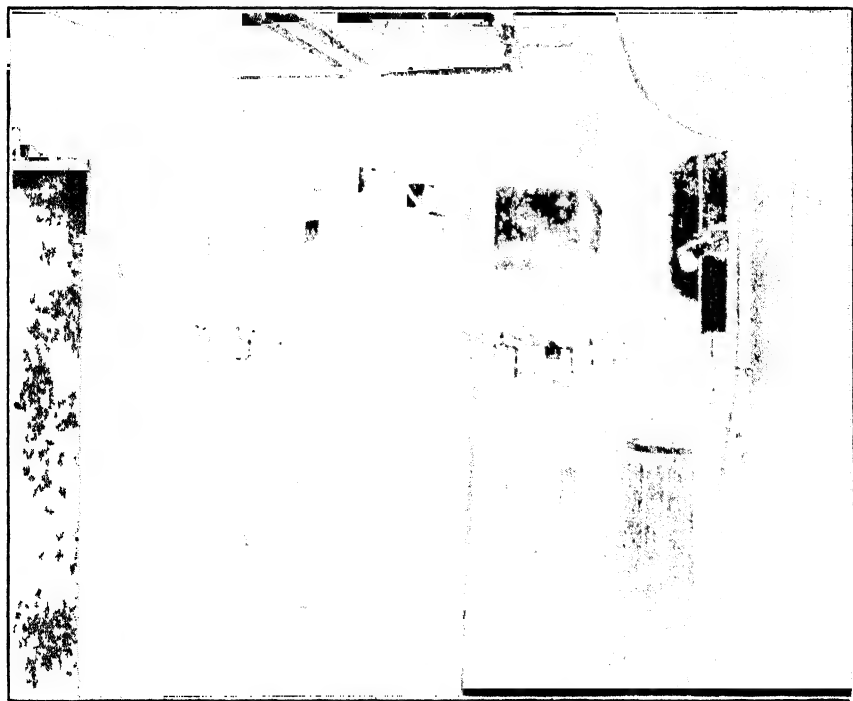



Fig. 4. Interior of rail grinding car.

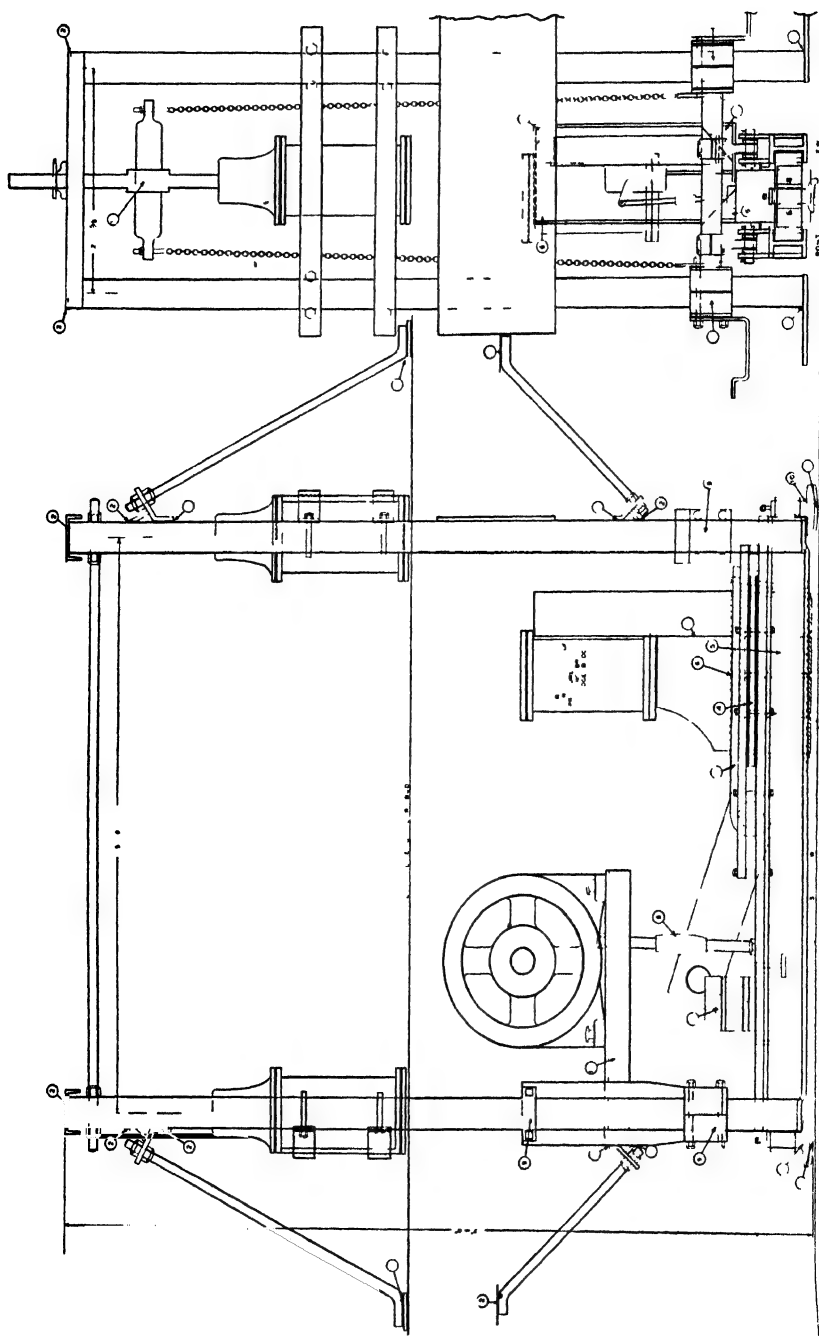



Fig. 5. Reciprocating rail grinder.

Satisfactory and economic results obtained from the use of this rail grinding car are as follows:

1. The rails of our car system may be ground as often as required.

2. The annual saving by the use of this grinder as compared to using our former portable grinder is $4,014, based on grinding 30,000 feet of single rail per year.

Cost analysis for 7-hour day:

	New Grinder 125 ft. Double Rail	Old Grinder 70 ft. Single Rail
Labor	$ 15.96	$ 14.77
Grinding Brick	8.88	2.22
Power Cost	2.64	.30
Maintence & Depreciation	1.25	.12
Total	$ 28.73	$ 17.41
Cost per 100 feet of rail	11.49	24.87
Cost per year (30,000 feet)	$3,447.00	$7,461.00

3. The complaints of noisy cars from residents and riders have decreased beyond our expectation. After having the grinder in service for six months, our complaint records show a decrease of 86 per cent in the average number of complaints per month as compared to the previous twelve month period.

In this instance arc welding made it possible for us to economically solve one of our problems in public relations. The actual value of benefit derived in this respect, of course, is incalculable; however, we feel that all efforts spent in maintaining good public relations pay dividends.

It is our practice, because of experience, to be adequately equipped to handle the numerous welding jobs of a simple and complex nature which arise on our property.

Equipment alone is not the answer to successful applications of arc welding. In addition to equipment, we have a capable welder who is capable because of his arc welding experience on a large variety of jobs, his ambition to keep up to date on the subject, and his eagerness to demonstrate the economy involved by the many applications of arc welding in the transit company.

Chapter IX—Fabrication of Steam Locomotive Cylinder

By Carl Ray Averitt,
Assistant Blacksmith Foreman, Paducah, Ky.

Carl Ray Averitt

Subject Matter: Why fabricate a steam locomotive cylinder? The author states that not only is there a saving of $983.21 per unit, but worn cylinders made of mild steel will be more easily machined when bushings are required. Further, should welding be necessary for repairs, higher quality work can be done, since cast steel often contains gas, slag and sand inclusions. Low carbon, open-hearth steel is selected for the purpose, free from seams and other defects. Each of the 129 parts of the entire assembly is then cut to shape and scarfed for welding with the torch. Steam-chest cylinder and main cylinder walls are then formed hot under the press. Parts, during welding assembly are held in place by spacers and brace bars.

Steel plate construction and fabrication like many other production practices, has been subjected to intense study. And, as in other producing methods, there have been vast and important improvements. All along the American industrial front, many practices and methods which served in ordinary times are being replaced by newer and better ways, which provide the three important factors to modern production—maximum utility, convenience, and economy.

Welding is definitely on the gain in the construction of bigger and better fabrications and especially so when so important a movement as National Defense is in progress. Not only are there more welds being made, but the technique and appliance has been rapidly improved.

Our company has found it economical and in some instances, since the war began, a necessity to fabricate many of its locomotive and car parts, since the manufacture of these type castings have been greatly curtailed. Several years ago this company found that there was really no end to the possibilities for cost reduction and product improvement with welding. It has in its continuous research found new discoveries in its welding application by which it is continually improving and modernizing its locomotives for higher speed and greater efficiency.

The company is using on its modern locomotives the application of the welding process either in whole or in part of fabrications and repair work at a great savings, and only vital parts restricted by various I.C.C. and A.A.R. regulations are exempt from welding. While the arc welding process is used to reclaim and repair main frames, smoke boxes, all kinds of spring and brake rigging, including equalizers, hangers and brake beams, cast steel cylinders, draw bar castings and supports, deck castings, truck frames, pilot beams, couplers and etc., among fabrications used on these locomotives, we might mention the names of some that have been used since the beginning of arc welding on railroads, while others are newer and improved. A few of the arc welded designed fabrications now in use are—air pump brackets, frame crossties, mechanical lubricator brackets, truck frames, pilots, cabs,

Fig. 1. Cylinder walls bent to shape.

pilot brackets, draw bar supports, engineers' and firemen's seats, steam pipe extensions, furnace bearers and pads, stoker troughs, stoker brackets, injector brackets, spring seats, grate shaker lever fulcrums, grate supports, reverse shaft arms, reservoir brackets, whistle rods, grate straps and ash pan latches.

In order to produce these fabrications to comply with the three factors of modern production, (maximum utility, convenience, and economy) first; the job to be made is given considerable thought and study so that as few parts may be used as possible, resulting in simplification and reduction in the amount of welding that may be done to produce the required strength and then prints drawn to conform with the results. Second; to select in advance sizes and types of material to be used. Third; size and kind of electrodes to be used in welding and, Fourth; the selection of qualified operators to perform the work with good equipment.

All these factors were considered when it had been decided to build the most interesting of all welded fabrications in our shop, a one-piece locomotive cylinder, to which the following subject matter is devoted. A class locomotive was selected that was to pull a crack passenger train at high speed. Drawings were made, either separately or in groups of each of the one hundred and twenty-nine parts to be used to fabricate the set of cylinders.

Material was selected according to I.C. specifications, sizes and kinds. A mild steel of low carbon content was used, metallurgically, a steel with an excellent weldability. As for all steel used by the company, certain chemical and physical properties were required. Chemical properties, as follows:

Carbon—not over .05 per cent
Phosphorous—not over .05 per cent
Sulphur—not over .05 per cent
Copper—not less than .20 per cent

Steel was to be made of open hearth process, free from seams and other defects. Each heat or melt to meet the following—tensile strength, pounds per square inch, 50,000 to 62,000; elongation in 8 inches, per cent not less than 1,500,000 divided by the tensile strength. Test specimens must bend

either hot or cold through 180 degrees over a diameter equal to its thickness, without sign of fracture and angles must open flat or bend shut, cold, without fracture.

After the material was selected, it was then delivered to the shop and each of the 129 parts to be used was cut to shape and scarfed for welding by an oxy-acetylene torch operating on a pantagraph table. After the desired plates were cut, the ones that required bending, such as the steam chest cylinder and main cylinder walls, were carried to a large hydraulic sectional flange press, heated, in a modern oil furnace and bent to shape by qualified blacksmiths and helpers, (See Fig. 1).

To cut the various 129 parts at the torch and bend those that required bending ready for welding, was done by the use of 338.5 man hours at a labor cost of $257.24. The weight of the material used was 12,921.3 pounds, and cost $941.07. The material was then transferred to the welding shop to be fabricated.

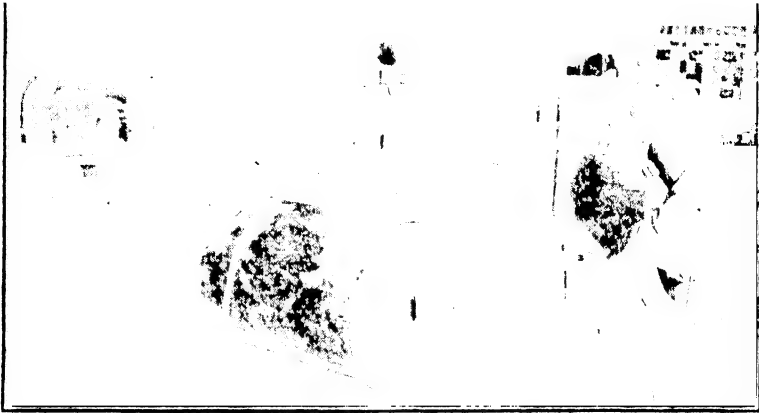



Fig. 2. Welding of cylinders.

All business is made up of men, material, and methods, and men count the most. Your product may be planned scientifically perfect and your materials the best, but without qualified, forward men, your product will be a failure and cannot endure. Our railroad believes this and all welding is done by welders who have passed specified tests at regular intervals. These welding operators are coached and taught that the use of proper electrodes as to size, type and analysis and the proper technique is the answer to most welding problems. By "technique" we mean the type of joint, the current control and speed of welding, position of welding, deposition of the beads, amount of preheat (if any) and the heat treatment after welding.

After two welders for each of the three working shifts had been selected to fabricate the cylinders, the various parts were then set up and made ready for welding. Some parts required fabrication themselves before the complete cylinder could be set up, such as the cylinders proper and steam chests. Also welding was required on the inside of the fabrication before the final piece could be applied. Before these parts could be fabricated into the complete unit, a very important factor had to be considered in its set up. That of contraction due to heat set up by the welded metal de-

Fig. 3, (left). Cylinders after welding. Fig. 4, (right). Close-up view of welded parts on cylinder.

posited. One-quarter inch was left to take care of the length and one-eighth allowed in width of the fabricated cylinder which proved in the end, very accurate. These parts were also held in place by spacers and brace bars to withstand any strain of contraction or pull, so that when job was completed it would be in line. To eliminate as much strain as possible the fabrication was welded uniformly, thus causing the contraction to be equally divided, (See Fig. 2).

To weld the complete unit, required 1,559.06 man hours (including all delays) at a labor cost of $1,402.18. (These figures for welding only). It required a total of 13,747 welding electrodes including three sizes, 3/16, 1/4, and 5/32, weighing 2,430.7 pounds at a cost of $148.32. Following is a table in detail of welding rods consumed:

Size	No. Rods Used	Wt. Lbs.	Cost
5/32	3,366	336.6	$ 21.03
3/16	6,777	1,093.0	69.73
1/4	3,604	1,001.1	57.56
Total	13,747	2,430.7	$148.32

After the completion of the welding the important factor of stress relieving was to be next. The one piece fabricated cylinder in the rough was then transferred back to the Blacksmith Shop from where it had formerly come, in the form of 129 pieces, but now fused to a solid unit. It was placed in a modern six burner, oil burning furnace to be normalized at a

Fig. 5, (left). After normalizing. Fig. 6, (right). Close-up of welds on cylinder.

temperature of 1550°F., that all stresses and strain might be relieved and the fabricated mass would be a solid unit retaining equal grain structure throughout.

From the normalizing furnace it was then transferred to the sand blast and sanded and then to the machine shop where the finishing touches were to be added and the surplus stock removed. Fig. 3 shows cylinders in rough after normalizing and Figs. 4, 5, 6, show close views of welded parts. Fig. 7 shows the completed part after machining and Fig. 8 a drawing of the cylinder.

To machine the cylinders for bushings, finish the steam chest, machine the smoke box saddle, drill and tap for cylinder head studs and machine cylinder head seats required 1,176.01 man hours including all delays, at a labor cost of $795.39. After the machine shop finished their job we had a completed cylinder, neat in appearance, strong and durable, fabricated and finished ready to go on locomotive at a savings of $983.21 over the cost of a cast steel cylinder

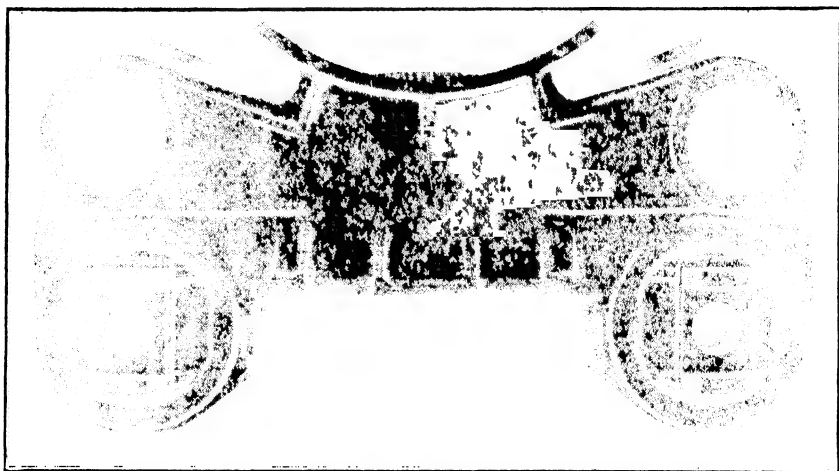



Fig. 7. View of cylinder after completion of machine work.

Why Fabricate a Steam Locomotive Cylinder?—I have already given data above that would encourage this practice if nothing else were considered. On the first set of cylinders to be fabricated, from the best of materials, a saving of $983.21 was made. Cylinders to be fabricated in the future will be easier. Prints have already been made and we know what has been required to build the first one. Difficulties experienced can be overcome, and short cuts missed at first can be used. Many parts of these cylinders can be cut from small pieces that would otherwise be scrap. Welding operators will be more familiar with this particular routine. All this will go to make even a greater savings.

The future upkeep must also be given consideration, which cannot be added directly as a savings but indirectly is just as important, and in some cases more important than the savings made from just fabricating the job. When cylinders return to the shop with the locomotive for general repairs, the reclaim job can be done at a minimum. The cylinders will be more easily machined to refit bushings than cast steel walls. Probably nothing else in the line of repairs for the cylinders will be necessary. If, however,

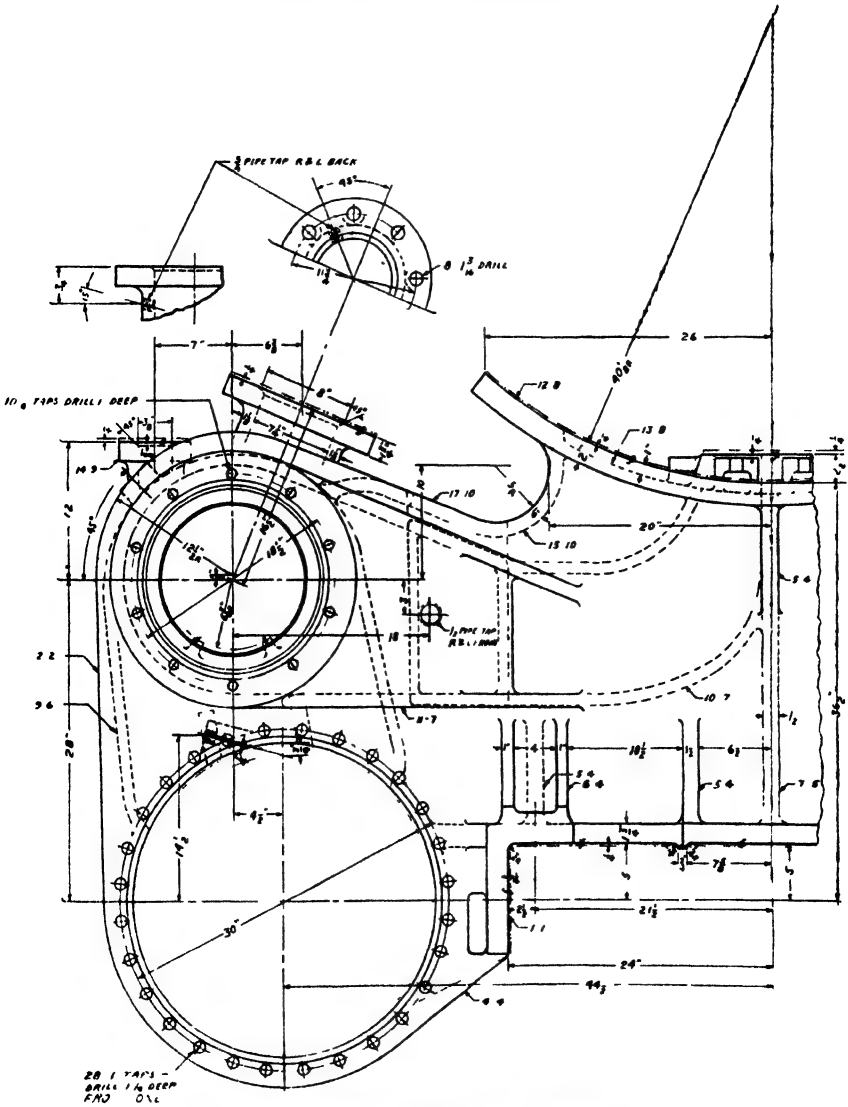



Fig. 8. Details of fabricated cylinder.

welding is necessary as is often times necessary in cast steel cylinders, it can be done with greater ease, producing a higher quality weld. Cast steel often times contains gas, slag and sand inclusions, thus it does not respond as readily to welding as a mild steel plate. These inclusions often times produce undesirable properties.

We cannot determine offhand the length of service that these fabricated cylinders will give as the one now in service has only been out a short time, but we do know that their life will be longer than cast steel, because the special selected steel has proven itself more durable and efficient on other fabrications now being used.

During the year of 1941, a total of 35 old cylinders were replaced by new cast steel cylinders at one shop alone. If these had been replaced by fabricated cylinders, at a savings of $983.21 per unt, a total savings of $34,412 would have been saved. This is a sum that cannot be "sneezed at". This amount would have given one and one half locomotives a class No. 3 repair and modernization. It would have paid for eight and one half new fabricated cylinders, or paid for 26,470 hours of welding.

No doubt but that in the near future all cylinders on our railroad will be fabricated. With an encouraging savings on the first one and greater savings on those to be made, and an increased durability of the product, fabricated cylinders are definitely on the gain.

In the end, whether it be with fabricated cylinders on high-speed locomotives or fabricated steel bodies for rail cars, it all sums up to the one now important phrase, quick and efficient transportation is the connecting link between war and victory—the railroads will keep 'em rolling.

Fabrication Data for One-Piece Locomotive Cylinder

LABOR—

	Man Hrs.	Cost
Blacksmith	338.5	$ 257.24
Welding	1,559.06	1,402.18
Machine	1,176.01	795.39
Other	9.3	8.04
Shop Exp.		763.51
Total	$3,082.87	$3,226.36

MATERIAL

Welding Rod	No. of Rods	Wt. Lbs.	Cost
3/16	6,777	1,093	$ 69.73
1/4	3,604	1,001.1	57.56
5/32	3,366	336.6	21.03
Total	13,747	2,430.7	$148.32

Steel used including two cylinder heads	$ 762.91
Oxygen used for cutting	16.65
Miscl.	13.19
Total all material	$ 941.07
Total cost labor and material	$4,167.53
Total cost of cast steel cylinder	$5,137.55
Total Savings	$ 983.21
Total weight of fabricated cylinder (Includes bushings and cylinder heads)	15,352 lbs.

SECTION IV
Watercraft

Chapter I—Hidden Advantages of Arc Welded Ship Construction

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Stanley A. Midnight

Subject Matter: The advantages of arc welding, as applied to ship construction, are not confined to reduction in costs. For example, with riveted construction, the hull friction may be as high as 14 per cent or even 22 per cent greater than for the welded shell. Again, insulation is more satisfactorily applied; deck coverings are not injured by underlying rivet heads which, even though countersunk, are objectionable; the design of ventilation ducts, plumbing and electrical facilities is simplified; and the difficulties of constructing masts and booms—especially of small diameter—are diminished. Detailed cost analyses of a large number of items show a large advantage is favor of welding amounting in the aggregate, over the industry at large, to $600,000,000. Time is also saved.

Practically every shipyard in this country for the past two years has been engaged in the construction of vessels for our government. Due to the restricted and confidential nature of this work, publication of any details regarding these vessels is forbidden by the government. It is felt that even in the absence of such a rule, as little information as possible should be published at this time.

Nevertheless, there are many phases of ship construction which may be said to be typical for all vessels. These are the standardized small practices which are in common use throughout the industry in the constructing of all types of ships, whether or not this construction be of a confidential nature.

A paper dealing with some later developments in these processes divulges no information concerning any particular vessel or types of vessels and can be of no special value to our enemies.

Rather, in the belief that a consideration of these developments may indicate many techniques that would make for a real savings in time, materials, and expense necessary to the victorious completion of our tremendous program, has this paper been prepared.

The arc welding designs given have been made and used on the various ships which my employer has constructed during the past two years. They may be applied to naval, maritime or commercial vessels. The costs of the redesigned arc welded details will be compared with the riveted details of former constructions.

The advantages of arc welding in the ship building industry are usually grouped, conveniently, into the one great advantage of weight reduction and its consequent reduction in cost. While this one advantage produces results
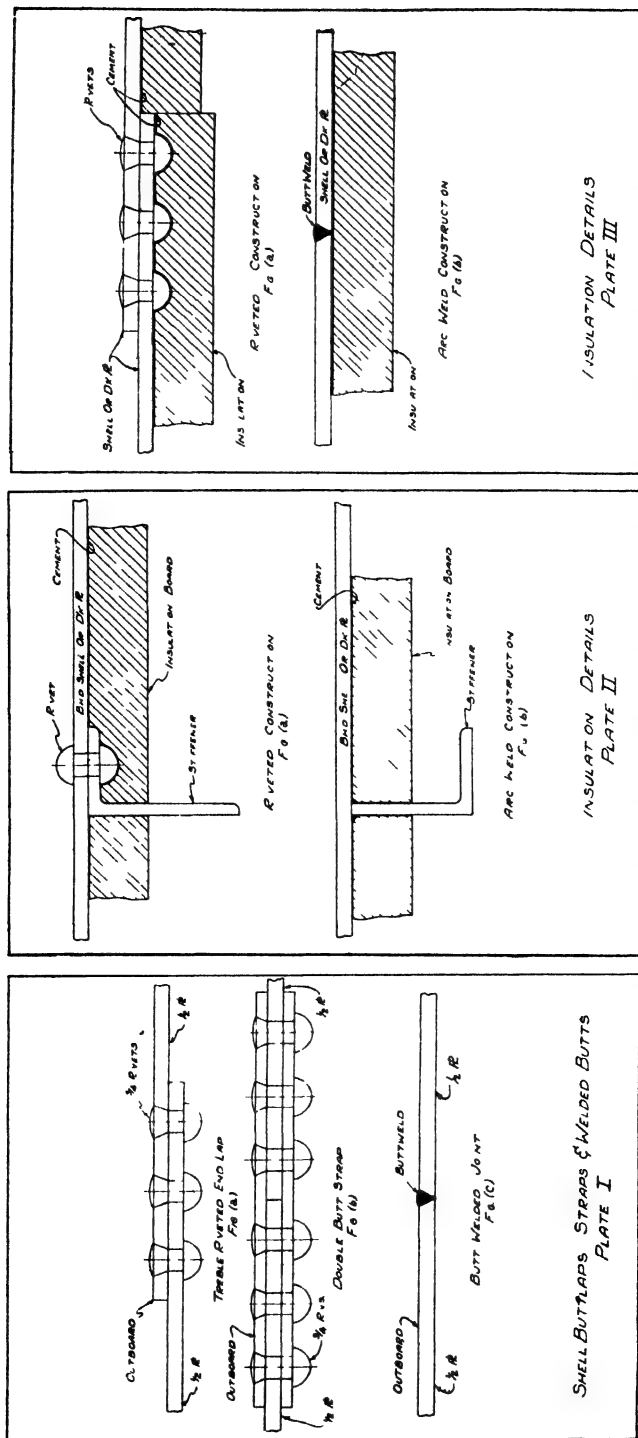
Fig. 1, (left). Shell buttlaps, straps and welded butts. Fig. 2, (center). Insulation details. Fig. 3, (right). Insulation details.

great enough in themselves to justify the arc welded ship construction, it is by no means the only advantage worth considering. There are many others which, while not as great in themselves as weight reduction, collectively represent an advantage of equal, or greater significance.

In this paper, various redesigns will be detailed, followed by comparative costs of the riveted and arc welded constructions. As progress is made in this great field of arc welded construction, it is found that the arc welded designs should be made not only for strength increase and weight reductions, but also to permit better and less expensive installations. For example, the installation of insulation or linoleum—a not inconsiderable item. Such advantages as these have been termed "hidden advantages" by the author. These numerous, less important items, added together, produce results which heretofore have not had proper weighing when arc welding advantages were considered.

Advantages of Arc Welded Constructions

I. Welded Shell Butts—Ships built of riveted construction generally had lapped plate seams and butts in the shell. The buttlaps, straps, and rivet heads contribute to the roughness of a vessel, increasing the friction of the ship. If this roughness is put in the form of a fraction of the total ship friction, authoritative estimates have placed the amount at from 14 per cent for a 400-foot cargo vessel, to 22 per cent for a 900-foot battle cruiser.

The protruding edges of the shell butt, straps, and rivets are a major part of the roughness of the ship's surface. The increase in the ship friction due to these, has been conservatively estimated at from 7 to 10 per cent for the average vessels. Therefore, it will be assumed that the elimination of the shell plate buttlaps, straps and rivets will reduce the ship friction at least 7 per cent. Fig. 1, figures (a) and (b) detail a typical riveted shell buttlap and strap respectively, while figure (c) details an arc welded butt joint. Note, for comparison, the simplicity of the arc welded joint as compared to the riveted one.

II. Insulation—In ship construction today, insulation is becoming more important and is being used in increasing amounts. In the early days, decks were made of wood or were steel covered with wood. Today, this construction has been largely replaced with steel decks requiring insulation below.

Insulation material may be any one of many trade materials, with cork and fibre glass the more common. The insulation is usually cemented directly to the steel. This requires cutting the insulation to fit between frames, deck beams, girders, and other stiffeners. Covering the stiffeners themselves is usually too expensive, so the insulation is generally applied between the webs of the stiffeners. In the case of the riveted construction (See Fig. 2, figure (a)) the insulation board must be coped out around the stiffener flange and rivets, involving considerable labor. Fig. 2, figure (b) shows an arc welded stiffener of a design which permits ready installation of insulation board, eliminating all coping as required for the riveted design.

Where insulation is applied between the riveted stiffeners, the board is often forced in place without being properly coped, thus effecting in the insulation board a tendency to spring out from the wall. This practice results in the insulation coming loose at these points and in time loosening entirely. An air space between the insulation and the steel permits the steel to sweat, thus allowing the water to gather and loosen the surrounding insulation. Insulation applied between the welded stiffener having no tendency to spring loose, adheres to the wall very well.

To properly insulate, insulation must be applied over seams, buttlaps, and straps of the shell, decks, and bulkhead plating, as shown in Fig 3, figure (a). Again the arc welded design, as shown in Fig. 3, figure (b) entirely eliminates the extra expense of this application.

Many times it is desirable to stop the insulation short of a deck or airport or around a door. Since these edges are vulnerable to damage, they are sometimes protected by a heavy-gauge Zee bar, as shown in Fig. 4, figure (a). The Zee bar in former construction was riveted onto the shell, bulkhead or deck.

The amount of work and procedure used in this installation of the Zee bar is as follows:

1. Zee bar is cut to length.
2. Rivet holes are punched.
3. They are then used for templates and holes drilled in the shell plate.
4. The holes must be countersunk from the outboard side.
5. The Zee bars are then bolted on.
6. Rivets are driven requiring a 3 man gang.
7. The rivets must be caulked.
8. The rivets must be tested for watertightness. Fig. 4, figure (b) details and angle toed to the shell and welded thereto to replace the Zee bar. This angle is as efficient as the Zee bar as far as holding the insulation is concerned. Following is an outline of the installation work required to install an angle:

1. Angle is cut to length.
2. Angle is welded in place by one man.

The two items above compare with the eight items in the riveted construction. The angle installed complete is no more work than the work of cutting and drilling the holes in the Zee bars. Items No. 3 to 8 of the riveted construction are excess work compared to the arc welded construction.

III. Deck Coverings—(a) Inside (Linoleum, Rubber and Compositions.)

Deck coverings of linoleum, rubber, or compositions manufactured under trade names present similar problems to those encountered in applying insulations. Fig. 5, figure (a), details a typical installation of linoleum over a plate seam. In this case a hard filler cement must be applied to ease off the joint to provide a relatively smooth surface.

The rivet heads, although countersunk, are never flush and produce a condition very undesirable. The linoleum laid over the rivets tends to loosen because of the slight protrusion of the head. Once loosened, the walking on the adjacent surface continues to break the adhesion between the linoleum and the deck, and in time much of the floor is loose, unsightly, and a safety hazard.

A flush arc welded deck, as shown on Fig. 5, figure (b), with butts ground smooth, forms a perfect base for the deck covering. An installation of linoleum as near perfect as possible is the result.

(b) Shell or Deck Coverings of Wood—On certain types of vessels it is necessary to sheath the shell or deck with wood. With a riveted shell and deck, the wood must be laid over the rivets, plate seams and butts. This requires fitting the wood over these obstructions. Fig. 6, figure (a) shows a typical installation of wood on a riveted deck contour. This fitting involves considerable labor expense.

Fig. 6, figure (b) details an arc welded deck design fitted with wood sheathing. Note the absence of special cutting and fitting normally required around the riveted joints.

(c) Safety Treads—In passageways adjacent to doors, safety treads are often placed to prevent slipping and excessive wear on the surface. These treads are fastened with flat head machine screws which screw into the deck.
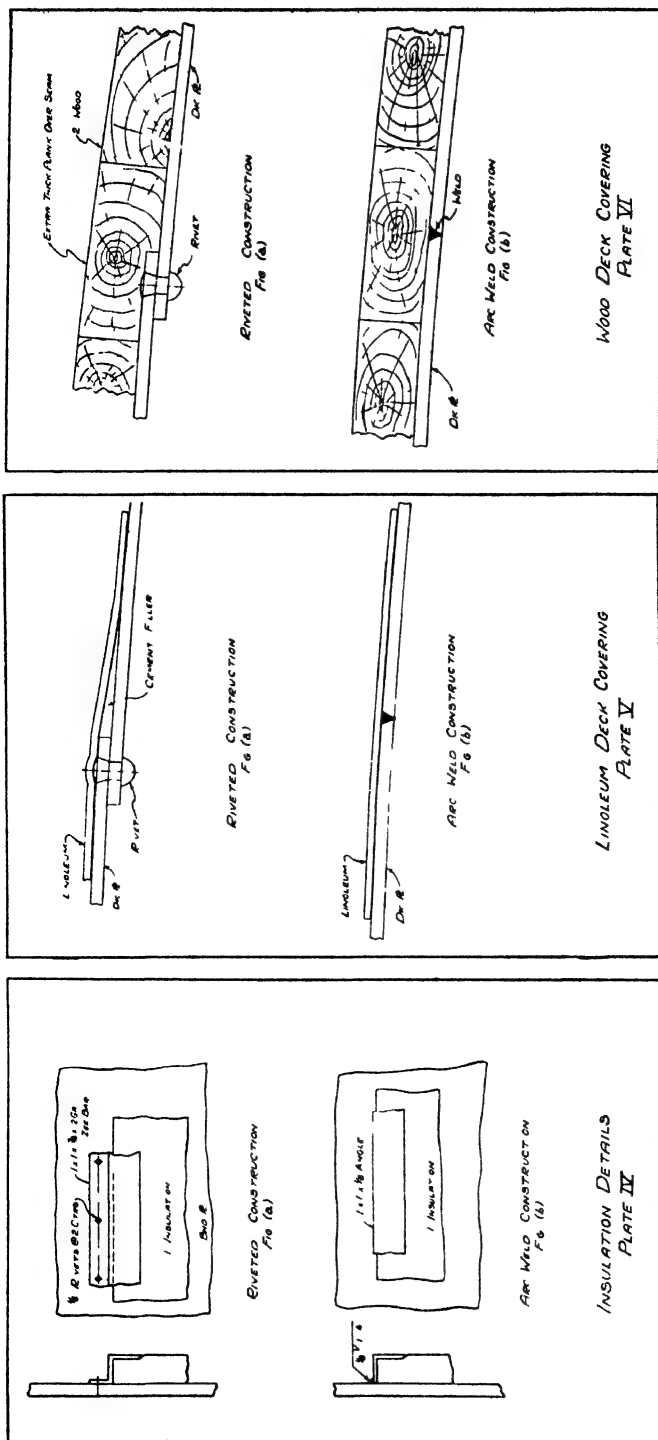
Fig. 4, (left). Insulation details. Fig. 5, (center). Linoleum deck covering. Fig. 6, (right). Wood deck covering.

Since the deck is not thick enough to provide sufficient threads for the screw, and since the connection must be watertight, round pads are welded below deck into which the screws are placed.

Riveted construction, however, calls for a doubling plate, below the deck, riveted and caulked. Normally, the treads are installed after the construction of the boat is well along, and hence a condition similar to that of installing Zee bars is encountered.

IV. Ventilation—The increasing importance of adequate ventilation has brought about a great many installation problems. The ventilating ducts must pass through watertight bulkheads and decks and therefore the duct itself must not only be watertight, but the joint at the bulkhead or deck must be watertight.

This problem is usually met with the installation of a so called spool at the deck or bulkhead, made of heavier metal than the ducts. Fig. 7, figure (a) shows a spool of riveted construction. The work involved in the installation is as follows:

1. Drill holes in bulkhead flange of spool.
2. Cut hole in deck.
3. Drill rivet holes in deck.
4. Ream holes.
5. Rivet (requiring at least 3 men and equipment).
6. Caulk rivets and flange.
7. Test.

The spool shown in Fig. 7, figure (b), details the arc welded construction and the installation work is as follows:

1. Cut hole in deck.
2. Weld spool in place (1 man).
3. Test.

In addition to the reduction in the amount of work as outlined above, note the fact that one welder does the work of the three riveters.

V. **Plumbing**—Fig. 8, figure (a), shows a typical stuffing box for a pipe passing through a watertight bulkhead or deck for riveted construction. Note the two castings and bolts and packing required. Fig. 7, figure (b), shows a pipe passing through a watertight bulkhead with arc welded construction. The construction is simple and inexpensive.

The two constructions compare as follows:

(a) Riveted construction.
   1. Make patterns.
   2. Purchase castings.
   3. Machine castings.
   4. Make special bolts and nuts.
   5. Drill watertight bulkhead for rivets.
   6. Rivet casting to bulkhead (3 men required).
   7. Install packing and remaining casting and tighten bolts.

(b) Arc welded construction.
   1. Weld pipe to bulkhead.

In the above comparison, work common to both constructions such as cutting the hole in the bulkhead for the pipe and testing, has been omitted.

VI. Electrical Work—Piping and ventilating ducts must pass through watertight bulkheads and decks just as electrical cables must pass through them. Again a stuffing box is used. However, for riveted construction this box must be riveted to the deck or bulkhead. This requires work similar to
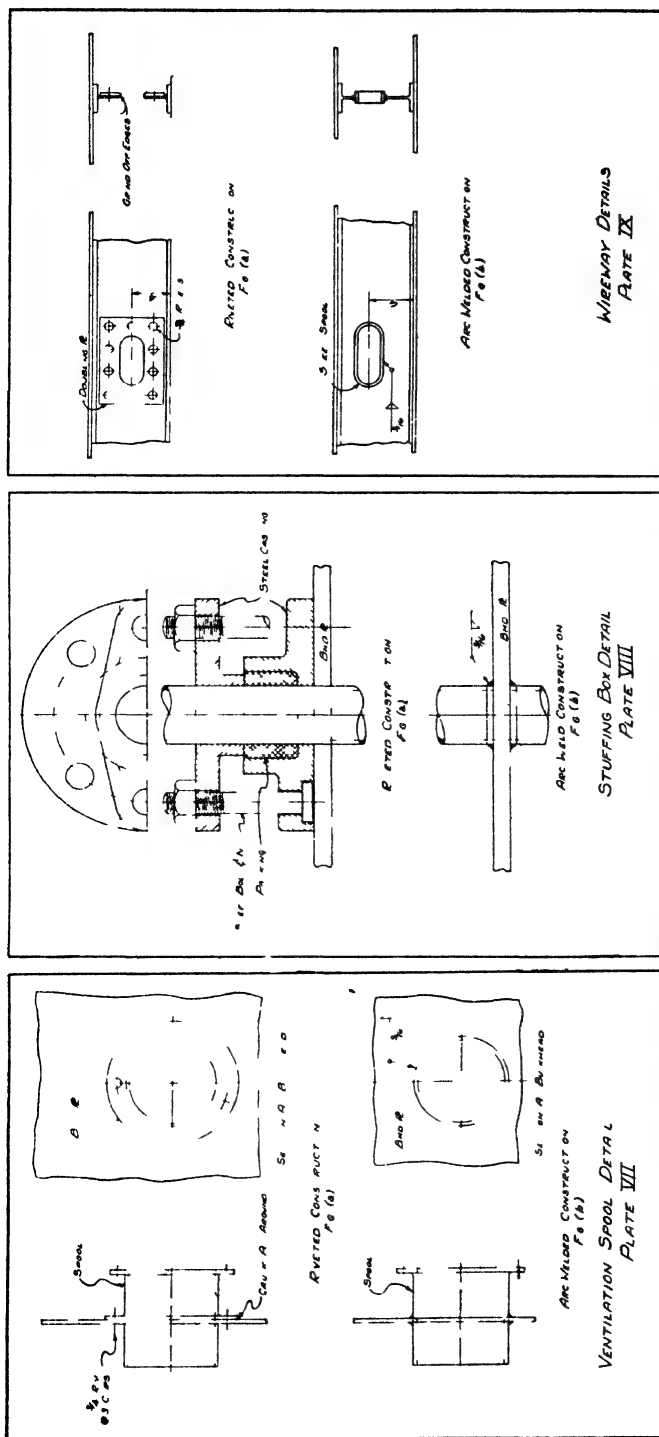
Fig. 7, (left). Detail, ventilation spool. Fig. 8, (center). Detail, stuffing box. Fig. 9, (right). Wireway details.

that outlined for stuffing boxes on piping. Arc welded construction simplifies this construction both as to material and labor.

In wiring a house, it is preferable to keep the wires between joists. The joists are drilled near the neutral axis and the wires pulled through. The advantage of this arrangement is that it protects the wiring and increases head room and clearances.

In a ship the same problems are encountered, so that it is very desirable to have the wires not only protected, but out of the way, eliminating unsightliness.

When holes are cut in beams or girders, they are necessarily weakened, and unless overdesigned to start with, they must be reinforced. Here arc welding is our handy remedy. Fig. 9, figure (a), details a wire way through a girder reinforced with riveted construction. Figure (b) shows the same girder reinforced with arc welded construction. Note first, the simplicity; second, the reduced amount of labor required for reinforcement; third, the finished job for desirability; and fourth, the appearance to the eye.

VII. **Mast and Boom**—(a) Mast Joint. Riveted mast construction has always been very difficult and very undesirable for small diameters. In recent years, welding has been employed to a great advantage, but, like many recent arc welded designs, the fullest advantage of this valuable art has not been realized.

Fig. 10, figure (b) shows a recent arc welded mast joint detail. The joint was arc welded, but employed the use of a casting. Fig. 10, figure (a), shows the detail of a mast joint designed by the author which is being used on ships now under construction. The joint consists of an intermediate size piece of pipe arc welded onto the smaller section of pipe and then inserted into the larger pipe where it is arc welded.

Here the author wishes to bring out the advantage of substituting pipe for a casting. The cost comparison already indicates the large savings possible. Arc welding permits these substitutions and it is this type of design which, when properly planned, produces the large savings.

(b) Boom Joint. Boom construction is comparable to mast construction in that castings may be eliminated similar to the mast joint through the use of a pipe.

(c) Shroud Pad Details. Fig. 11, figure (a), details a shroud pad attached to a mast. The detail consists of arc welding a pad cut from a plate, into the mast. Fig. 11, figure (b) details a pad of riveted construction. This pad is a steel casting slipped over the mast and riveted to it. To install this pad it is necessary to have a joint in the mast close to the shroud pad so that the rivets can be driven.

VIII. **Expanded Metal Construction**—A former construction of expanded metal partitions, as shown in Fig. 12, figure (a) involved the protrusion of the mesh ends through the channel frame and bending them in place. This required the drilling of many holes and insertion of the ends of the mesh through the channel, which is a tedious task. Figure (b) details an arc welded construction currently being used by the author's employer. After the frame is built, the mesh is inserted and tack welded. A very simple operation, when compared to the method used in the former construction.

IX. **Miscellaneous Deck Fittings, Bitts and Cleats**—(a) Bitts. Fig. 13, figure (a) details a Bitt of cast steel which was riveted to a deck. In order to obtain sound castings, the wall had to be made heavier than otherwise necessary. Figure (b) details a bitt made of arc welded construction built of pipe and plate. This bitt is as serviceable as the cast one and is of much
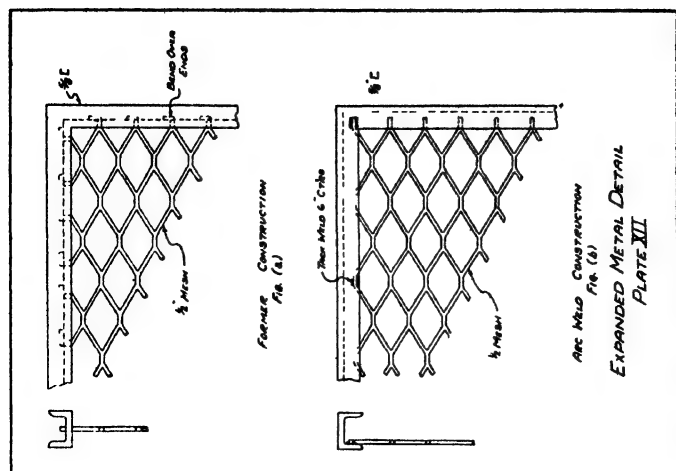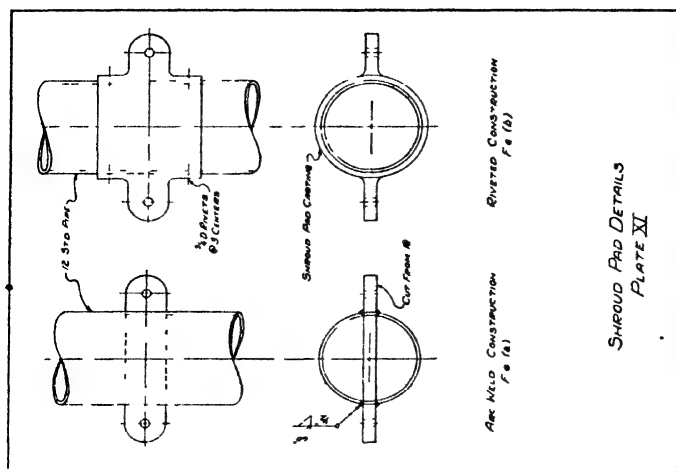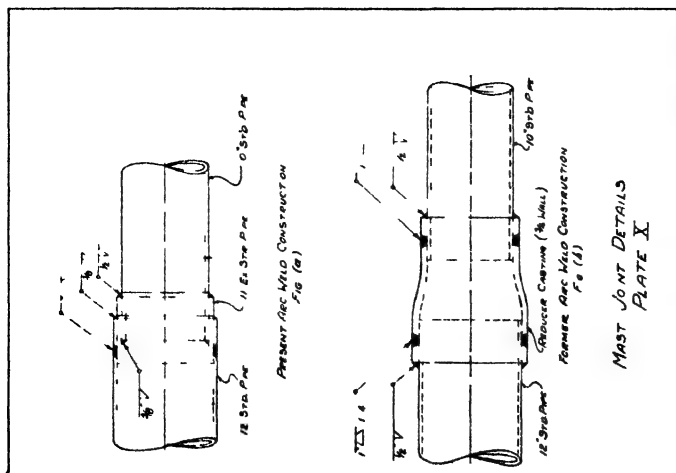
Fig. 10. (left). Details, mast joint. Fig. 11. (center). Details, shroud pad. Fig. 12. (right). Detail, expanded metal.

lighter construction. The comparative weights are 432 and 117 pounds for the cast and arc welded bitts respectively.

In addition to the saving of the cost of the bitts themselves, the casting had been riveted to the deck, while the arc welded bitt is welded down.

(b) Cleats—Fig. 14, figure (a), details a cast steel cleat for arc welded construction. Of course, the cast steel cleat designated for riveted construction could be welded to the deck which in many cases was an intermediate step to proper arc welded construction.

The base, however, adds no strength to the cleat and is nothing more than excess material which was required for riveting and which is not required for arc welded construction.

Cost Comparison—Figs. 1 to 14 detail various designs substituting arc welding for former types of constructions. In some cases, the new design replaces a former arc welded construction, in others riveted construction, and in still others a casting replaces a former casting.

Shipbuilding involves many trades and there is considerable equipment made in the shipyard for the vessels. The usual method of cost accounting followed in the shipyards is to group the various items such as deck fittings. Unless these items are purchased, there is no record as to the exact cost of a cleat, bitt, or chock for example. Therefore, to compare former constructions with new ones it is necessary to compute the cost from available cost figures. This method will be employed where necessary in this cost analysis or comparison. Some cost figures are available and in these cases will be used.

In an established shipyard, patterns for many standard fittings are available and where this is true, no costs will be included for patterns. Where special patterns are required which will not be used again, the cost of patterns will be included.

The costs will be computed for a single item even though its use is repeated many times. For example, the pipe stuffing box may be used many times for each of the various sizes of pipe.

Fig. 1—Shell Buttlaps, Straps and Welded Butts—As stated in Item I, the ship's friction is reduced 7 per cent through the use of arc welded plate butts. This will permit a reduction in shaft horse power of that amount and still maintain the same speed. A 7 per cent reduction in shaft horse power may reduce the cost of the power plant 7 per cent or more, depending on the particular vessel. This gives a proportionate cost savings of 7 per cent.

Figs. 2 and 3—Insulation Details—The cost of applying insulation board over riveted construction is approximately $.12 per square foot, while the reduction in labor involved due to the use of arc welded construction reduces this cost to $.085 per square foot. This gives a proportionate savings of 29 per cent for this work.

Fig. 4—Insulation Details.

Riveted Construction Costs
Figure (a)

Item	Rate	Cost
Zee Bar per foot		$ .05
6 Rivets		.02
Driving	@ $5.00 per C	.30
Drilling Holes	@ 2.50 per C	.15
Countersinking	@ 1.50 per C	.09
Bolting	@ 2.50 per C	.15
Caulking	@ .04 per ft.	.04
Total per lineal foot		$ .80

Arc Welded Construction Costs

Figure (b)

Angle	.8# @	.025	.02
Arc Welding	.25′ @	.08	.02

Total per lineal foot .... $ .04
Savings per lineal foot .... $ .76
Proportionate Cost Savings 95%

Fig. 5—Linoleum Deck Covering—The elimination of the extra work involved in preparing the deck for laying linoleum has reduced the cost from $3.00 to $2.25 per square yard, including the linoleum. Allowing for the cost of the linoleum, the comparative costs of laying the linoleum would be $1.50 and $.75 respectively. This represents a saving of $.75 per square yard, or a proportionate cost savings of 50 per cent on the work of laying.

Fig. 6—Wood Deck Covering—Wood Decking or shell sheathing laid over riveted construction costs about $.32 per square foot for installation of a decking 2 inches thick. When the shell or deck riveted seams and butt-laps are eliminated, this cost is reduced to $.25, making a saving of $.07 per square foot or a proportionate cost saving of 22 per cent.
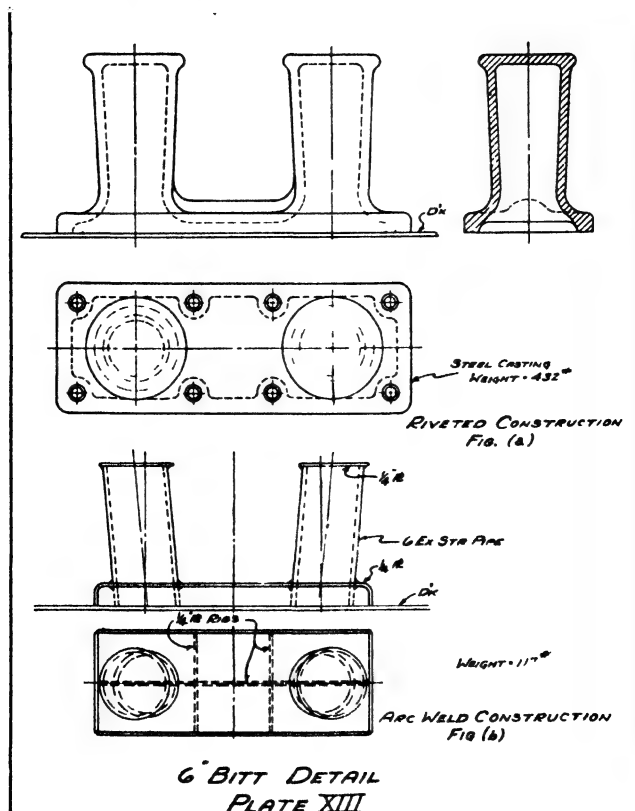
Fig. 13. Detail, 6-inch bitt.

Fig. 7—Ventilation Spool Details.

Riveted Construction Costs

Figure (a)

Item	Quantity	Rate	Cost
Extra flange on casting	11#	@ $ .15	$1.65
Machining	1 hr.	@ 1.12	1.12
Rivets	16	@ .01	.16
Driving		@ 6.00 per C	.96
Drilling		@ 2.50 per C	.40
Bolting		@ 1.50 per C	.24
Caulking		@ .04 per ft.	.12
Total			$4.65

Arc Welded Construction Costs

Figure (b)

Item	Quantity	Rate	Cost
Arc Welding	2 × 3′	@ $.14	$ .84
Savings			$3.81
Proportionate Cost Savings			82%

Fig. 8—Stuffing Box Detail—Since the stuffing boxes are made standard for the various size pipes, no allowance will be made for the patterns required.

Riveted Construction Costs

Figure (a)

Item	Quantity	Rate	Cost
Castings	22#	@ .23	$5.04
Bolts & Nuts			.84
Packing			.06
Rivets	8	@ .43×.03	.11
Driving	8	@ .05	.40
Drilling & Punching	8	@ .025	.20
Bolting Up	8	@ .015	.12
Caulking	2.5′	@ .04	.10
Remaining Installation			.85
Total			$7.72

Arc Welded Construction Costs

Figure (b)

Item	Quantity	Rate	Cost
Welding	1.25′	@ .10	$ .13
Savings			$7.59
Proportionate Cost Savings			98%

This saving is almost the entire cost of the stuffing box and installation.

Fig. 9—Wireway Details.

Riveted Construction Costs

Figure (a)

Item	Quantity	Rate	Cost
Fabricating Plate	.8 × 15.3#	× .10	$1.22
Riveting Complete	10	@ .11	1.10
Total			$2.32
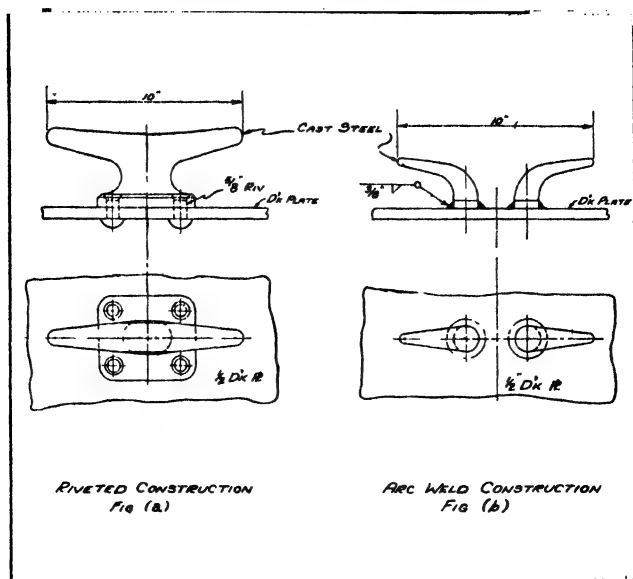
Fig. 14. Detail, cleat.

Arc Welded Construction Costs
Figure (b)

Spool Casting	2#	× .32	$ .64
Welding	2 × 1.5′	× .10	.30
Total			$ .94
Savings			$1.38
Proportionate Cost Savings			59%

Fig. 10—Mast Joint Details.

Former Arc Welded Construction Costs
Figure (b)

Casting	170#	@ $ .16	$27.20
12″ Standard Pipe	.5′	@ 2.25	1.12
10″ Standard Pipe	.5′	@ 1.64	.82
Total			$29.14

Present Arc Welded Construction Costs
Figure (a)

10″ Standard Pipe	.92′	@ $1.64	$ 1.51
12″ Standard Pipe	1.0′	@ 2.25	2.25
11″ Ex. Strong Pipe	.75′	@ 3.00	2.25
Total			$ 6.01
Savings			$23.13
Proportionate Cost Savings			79%

Welding costs have not been computed, as they have been assumed to be equal, although the costs in Figure (a) would be somewhat less than for Figure (b).

Fig. 11—Shroud Details.

Riveted Construction Costs
Figure (b)

Casting	154#	@	$ .16	$24.60
Machine work	5 hrs.	@	1.12	5.60
Riveting	24 riv.	@	.11	2.64
Total				$32.84

Arc Welded Construction Costs
Figure (a)

Shroud Pad Steel	42#	@	$ .06	$ 2.52
Burning Hole in Mast	2.2′	@	.08	.18
Welding	2.2′	@	.92	2.02
Total				$ 4.72
Savings				$28.12
Proportionate Cost Savings				86%

Fig. 12—Expanded Metal Detail.

Former Arc Welded Construction Costs
Figure (a)

Drilling Holes & Assembly per square foot .... $ .08

Present Arc Welded Construction Costs
Figure (b)

Arc Welding	$ .03
Savings	$ .05
Proportionate Cost Savings	62%

Fig. 13—Bitt Detail.

Riveted Construction Costs
Figure (a)

Casting	432#	@	$ .16	$69.30
Machining	4½ hrs.	@	1.12	5.04
Riveting	8 rivets	@	.15	1.20
Total				$75.54

Arc Welded Construction Costs
Figure (b)

Pipe	2 × 1.25′	@	$1.27	$ 3.20
Plate & Fabrication	47#	@	.10	4.70
Welding	18′	@	.11	1.98
Total				$ 9.88
Savings				$65.66
Proportionate Cost Savings				87%

Fig. 14—Cleat Detail.

Riveted Construction Costs
Figure (a)

Casting	15#	@	$ .27	$4.05
Machining	1½ hrs.	@	1.12	1.68
Riveting	4	@	.11	.44
Total				$6.17

Arc Welded Construction Costs

Figure (b)

Castings	2# @	$ .32	$ .64
Welding	67′ @	.18	.12
Total			$ .76
Savings			$5.41
Proportionate Cost Savings			88%

Table I—Summary of Costs

Fig. No.	Unit Cost Former Construction	Unit Cost Present Construction	Savings	Proportionate Cost Savings
1				7%
2	$0.12/sq. ft.	$0.085/sq. ft.	$0.035/sq. ft.	29%
3	.12/sq. ft.	.085/sq. ft.	.035/sq. ft.	29%
4	.80/lin. ft.	.04/lin. ft.	.76/lin. ft.	95%
5	1.50/sq. yd.	.75/sq. ft.	.75/sq. yd.	50%
6	.32/sq. ft.	.25/sq. ft.	.07/sq. ft.	22%
7	4.65	.84	3.81	82%
8	7.72	.13	7.59	98%
9	2.32	.94	1.38	59%
10	29.14	6.01	23.13	79%
11	32.84	4.72	28.12	86%
12	.08/sq. ft.	.03/sq. ft.	.05/sq. ft.	62%
13	75.54	9.88	65.66	87%
14	6.17	.76	5.41	88%

Conclusion—Normally, one thinks of the advantages of arc welded ship construction as being limited to increased strengths and a decreased hull weight which permits greater pay loads. These thoughts are widespread and much effort and time has been devoted to the improvement of these design details.

However, there are other advantages such as the savings in machinery costs or the reduced installation costs of deck coverings or insulation. These additional savings are possible through the application of such arc welded designs as are outlined in this paper and have been termed "hidden advantages" by the author.

The cost savings have been summarized in Table I for each of the various redesigns. As will be noted, the arc welded construction shows a proportionate cost savings of from 7 to 98 per cent. Since each of the various details are repeated many times over in a vessel, the total savings accruing from these designs amount to 2½ per cent of the vessel cost.

There are many similar designs which, for the lack of time in preparing such a large project, have not been detailed. If these additions are included, a total cost savings of about 8 per cent of the vessel's cost is possible.

Based upon the work under contract by my employer, cost savings of approximately $3,500,000 will be realized through the adoption of the arc welded constructions outlined in this paper.

The total estimated cost savings accruing to the shipbuilding industry through this adoption of arc welded construction would amount to $600,000,000 annually.

In addition to the advantages already mentioned in this paper, there are many others which are as follows:

1. Arc welding constructions produce simplicity, which is modern and eliminates unsightliness.

2. Safety hazards, such as loose linoleum on a deck are eliminated, saving life and expense.

3. Increased service life is the result of better initial installations of deck covering and insulation.

4. Less time is required for construction, which is very important at this time.

Much progress has been made in the past, much progress is being made today, and more progress will be made in the future in this great field of arc welded construction. In fact, the improvements in ship construction have been so tremendous since the inception of arc welded construction that it might be said in conclusion that modern day ships could not be built without it.

Chapter II—Quantity Production of Cargo Carriers

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George W. Hawkins

Subject Matter: This is a rather complete proposal for the establishment of a shipyard to build standardized 100% welded cargo carriers of any size up to 500 feet, in which the concept of prefabrication is carried much farther than in any existing yard. All curved plates are formed under the hydraulic press; frames are bent cold and cut to length, all parts, including sub-assemblies being made with sufficient accuracy to avoid fitting. A moving assembly line completes the picture of technique familiar in other industries (e.g. automotive) applied to ship construction. Savings of 37.5% of existing costs are claimed and a production capacity of one ship per shift anticipated.

I, Summary—This paper presents general designs and estimates of cost and performance for a shipyard for producing cargo carriers in quantity. The plant, as described and illustrated, is the result of an extended period of research by a group of engineers, naval architects, ship-builders, production specialists, industrialists and others. It is of unique design possessing many characteristics and utilizing many methods and processes entirely foreign to the usual conventional shipyard. The pertinent facts are summarized as follows:

(1), Size of Ships—The plant will produce standarized welded cargo carriers in any size up to 550 feet in length.

(2), Prefabrication—The idea of prefabrication has been carried much further than in any existing shipyard. Complete keels and larger portions of completed bows, sterns, double bottoms, sides, bulkheads, decks and superstructures are prefabricated separately and simultaneously. These parts are made in sections weighing from 90 to 300 tons each.

(3), Prefabrication Space—This extensive and simultaneous prefabrication requires an immense platen area—many times that employed in our most progressive present day shipyards. This large area has been subdivided and disposed so that each part is available where and when required for assembly into the complete ship, requiring minimum handling. The entire fabricating space is enclosed and roofed in order to facilitate continuous production and to eliminate unnecessary delays.

(4), Warehousing—The warehousing arrangement is unique. Not only is the warehouse space far greater than usual, but it is arranged and equipped so as to make each piece of equipment and material and each kind of supply available just where and when they are needed. This calls for the separate storage of each kind of equipment, material and supply, and the segregation of these in the exact quantities required by the ship so that they will be ready for delivery to the ship exactly when required and with minimum handling.

(5), Crane Capacities—Crane capacities are greatly increased throughout all departments as compared to any existing shipyard. These range up to as high as 300 tons depending upon requirements in each case. There are many cranes of 100 tons capacity. These crane capacities are necessary in order to handle prefabricated parts of the sizes contemplated.

(6), Plate Forming—All curved plates are cold formed and cut to exact size and shape by means of powerful hydraulic presses and steel dies. This is a far cry from the crude laborious methods in general use in the conventional yard. Plates are accurately and rapidly formed and cut by this method. There is little need, therefore, to compromise with the hull design in order to reduce cost or increase speed of production, because a ship of excellent lines can be built just as cheaply as one of square and triangular sections.

(7), Frame Forming—Frames are cold bent, notched and cut to length by hydraulic press and forms—a far quicker and more accurate method than that usually employed.

(8), Production Line—Ship erection is on assembly line instead of on the usual shipway, so that work is brought to the men instead of men to the work. This means a highly trained force for repetitive operations with a consequent saving in man hours required. No cutting or fitting is necessary on production line as all parts and sections are precision made.

(9), Fixtures—All sub-assemblies as well as the ship on the main assembly line are built to an accurate system of steel fixtures so as to save time in assembly fitting and to insure accuracy of all parts and of the completed ship.

(10), Distortion Control—Unusual means are employed to minimize distortion of parts and of the ship due to internal stresses incurred while welding. Included among these methods is a system of cooling in such a manner as to confine the heated portions of the metal to minimum areas.

(11), 100 Per Cent Welding—The hulls and superstructures are to be 100 per cent arc welded. No rivets whatever are used. Modern welding methods and results make this plan feasible. This means a lighter finished ship, greater cargo carrying capacity and lower resistance (hence less power required) for a given speed. Furthermore, the millions of rivets needed for large ships would slow up production to such an extent as to render impracticable a real production plan of this type.

(12), Complete Plant—The proposed plant will have facilities for the production of main and auxiliary engines as well as a certain portion of the required auxiliary equipment usually obtained from outside sources. The plant will be more nearly self-contained than any existing shipyard. It will produce its own forgings and gears and its own steel, iron, brass and aluminum castings. In addition to the production portion of the plant proper the equivalent of 19 conventional shipways have been provided, most of which are available for use as dry docks.

(13), Launching—Launching is by means of electric locomotives and a system of locks instead of the usual launching ways.

(14), Completion Before Launching—Ships are completed and outfitted before launching. All parts of exterior and interior are accessible until the ship is launched. There is no need for the usual drydocking after trials.

(15), Use of Scrap Metal—Scrap metal from shipbuilding operations will be used in the iron and steel foundries, thus effecting a further material saving in cost and in time of construction.

(16), Incidental Facilities—Unusually complete hospital, first aid, locker rooms, restaurant and canteen systems are included.

(17), Plant Output—On the basis of three shifts per day and 360 days per year, the plant will have a capacity to produce 6,000,000 dead weight tons of shipping per year, or more if the size of the ship is increased beyond that used for comparative estimating purposes in these pages.

(18), Comparative Output—Compared with the proposed plant, the conventional shipyard (based upon highly efficient management and the most modern facilities) would require not less than 290 shipways in order to produce the same 1156 ships per year of the same design.

(19), Investment—The estimated cost of land, plant and equipment complete for the proposed production plant is $150,000,000.

(20), Comparative Investment—According to figures provided by the U. S. Maritime Commission, the first cost of 290 shipways with the necessary outfitting docks, shops, warehouses, yard equipment, etc., would amount to $435,000,000, or nearly three times that of the proposed production plant of equal capacity.

(21), Saving in Production Costs—The production plant will operate at a great saving in cost of ships produced as compared with the cost of similar ships built in the conventional yard. This saving will amount to over $500,000,000 per year which is equivalent to over one-third of present cost.

(22), Saving vs. Investment—From (20) and (21) it follows that the proposed plant will pay for its entire first cost in savings effected in less than four months' operation.

(23), Other Types of Vessels—It will be quite feasible to produce naval vessels in certain categories, if desired, at comparable speeds of production and at large savings in cost. These could include submarines, sub-chasers, corvettes and destroyers. Tankers also could be produced readily in this plant.

(24), Time Required for Completion—The plant can be in full production within twelve months from date of approval.

II, Purpose—The present day conventional shipyard is the outgrowth of the experience of several hundred years. It represents, probably, the best method of building ships for the conditions which brought about its development. These conditions call for a plant capable of turning out an almost endless variety of ships, as regards size, type and design, to suit a long list of requirements, and also to suit the personal whims of the ship owner and Naval Architect. The necessity of meeting these multitudinous conditions has brought about a jobbing type of plant as contrasted to a production plant and this jobbing plant is characterized by all of the inefficiencies, high cost operations and slow speed of production which are inherent in other jobbing shops in all lines of manufacture. In fact, the size and weight of the ship structure, its complication and intricacy of detail and the waterfront conditions under which it is built have combined to produce a particularly slow and wasteful method of manufacture.

The World War has now changed conditions radically. The prime desideratum is not the building, by slow relatively wasteful methods, of every conceivable size, type and design of ship, but it is the production of the maximum tonnage possible in the shortest time and at the lowest cost. The first obvious step in such a program consists of adding to existing shipyards as many additional shipways, outfitting docks, shops, warehouses, dry-

docks, etc., as conditions will permit. The second step is the establishment of new shipyards at such locations as seem feasible from physical, managerial and labor standpoints. These two steps have been taken already by the United States Maritime Commission.

The purpose of this paper is to outline a further step which it is felt would be highly advantageous under existing conditions, and which would effectively supplement the steps already taken. This step consists of the building of a continuous production shipyard designed and equipped to produce cargo-carriers or other types of vessels, if desired, in quantity, at a high rate of speed and at minimum cost. Such a program calls for definite standardization.

Fig. 1. General arrangement of shipyard.

This paper describes and illustrates such a plant. It presents estimates showing the investment required. It indicates the rate of production to be expected. It compares the cost of shipbuilding by present conventional methods with the cost of the finished ship produced by the proposed method.

The art of shipbuilding has continued for a long period of years in a static state. Until the last three or four years, very little in the way of fundamental improvement either in equipment or method has been introduced. For years this industry fought tooth and nail the application of arc welding to the construction of ship hulls and superstructures, in spite of the known advantages of weight saving and lower cost of fabrication to be realized. It was not until the last three or four years that this prejudice was

overcome, and as a matter of fact, it is not entirely overcome at this date. However, the adoption of arc welding to a varying extent by the majority of shipbuilders marked the first big improvement in shipbuilding in several decades and in turn made possible further improvements to follow.

The next steps are just now in process of development. The foremost of these is a tremendous increase in the quantity of prefabrication. The old time "fab shop" has been increased many fold both in size and number so that parts for a single ship can be fabricated in several places at one and the same time. In this way a larger number of workmen can be employed on the construction of one ship than is possible where each piece is fitted on the ways, and in addition, the work can be performed in more convenient and satisfactory positions than are possible when working in the hull itself. Down welding is substituted for overhead and vertical welding. The net result is a further material saving in time and cost.

This expansion in prefabrication calls for a large increase in ground area per shipway so that the old time shipyard with its already crowded and inadequate shops and storage facilities is often physically unable to take advantage of the newer methods.

The next improvement sprang directly and naturally from the increased prefabricating facilities. This consisted of prefabricating larger and larger parts. This "before the ways" type of heavy construction is just now being evolved. In one western shipyard an entire superstructure is prefabricated and handled in one piece from welding platen to ship by a special 200 ton crane. Here again the old yard is handicapped by the relatively low crane capacities usually installed.

The production plant described herein utilizes all of the latest developments in shipbuilding practice and carries them to a much further point than has heretofore been done, and in addition new methods are described for still further reducing costs and increasing production rates.

The data in this report are presented as a contribution which, it is hoped, may be one of the determining factors in the outcome of the present World War.

III, Description of Plant—In general, the proposed plant consists of a production line upon which the ships are assembled; production departments and warehouses in which sections of the ships and equipment therefor are produce and/or stored; a system of locks for the launching of the ships and for the admission of outside ships to drydock for painting or repairs; shipways for the building of ships somewhat in the conventional manner; shops for the production of forgings, castings, gears, Diesel engines, piping, sheet metal work, fabricated parts and other equipment; miscellaneous buildings and equipment including power station, water supply, fire protection, compressed air plants, oxygen-acetylene plant, paint shops, locker rooms, offices, hospital, cafeteria, gate houses, etc.; distribution systems for power, light, fuel, water, air, oxygen, acetylene, etc.; and the required roads, railroads, parking areas, wet docks, watch towers, fencing and other necessary yard improvements.

The general arrangement of the proposed plant is shown upon drawing, Fig. 1, and sections through various portions of the plant are shown upon drawing, Fig. 2.

Production Line—The production line is about 14,000 feet long. It is divided into two sections each of approximately the same length. The first section starts at a series of shops where are produced trucks, carrying sad-

dles, fixtures, and keels; and ends at a transfer table where the ship is transferred to the return production line. This return line or second section terminates in a system of launching locks.

The production line proper consists of seven runs of steel trackage mounted upon reinforced concrete foundations which in turn are supported by creosoted piling. These tracks carry specially designed structural steel trucks, each truck being 70 feet wide and 80 feet long carried on 56 wheels. Several trucks are combined to form one structure, the number depending upon the size of ship being produced, and this structure moves along the line continuously at a very slow rate of speed. This rate will vary with the length of ship being constructed, but generally will be such as to provide for the launching of one ship per day for ships 350 feet long, somewhat less frequent launchings for longer ships, and more frequent launchings for shorter ships.

The ships are to be built by precision methods to a rigid system of templates and fixtures. The fixtures are mounted upon the trucks and form a part thereof.

Shipways—Near the upper end of the production line adjacent to the upper transfer table there will be located six take-off ways. The transfer table is so designed that ships under construction reaching the upper end of the production line may be transferred to the return line, or, if it is necessary or desirable, to one of the six take-off ways. This feature adds a certain flexibility to the production line.

At the lower end of the production line a transfer table is also provided which allows for the ship to go to one of three places: (1) to the launching lock where it is launched by a method to be described later, (2) to one of seven finishing ways where it may be stored while paint is drying or for any changes which may seem necessary, or (3) to any one of six ship-building ways where it may undergo major changes if these are required. This makes a total of 19 shipways where ships may be altered, repaired or built by the usual methods; and where any ship, not required in sufficient quantities to justify cost of forms and fixtures, can be built by conventional methods.

Locks—There are two sets of locks, one set for the launching of completed ships from the production line; and one set for the admission of outside ships of any size or type, permitting such ships to be raised to the level of the shipbuilding docks and drydocked therein for required repairs.

The two sets of locks are provided with centrifugal pumping equipment for filling and emptying the locks, one into the other or either into the sea. The complete operation of launching, including time required for hauling ship and its supporting trucks into place in upper lock, closing of lock gates, flooding with water until ship floats, towing ship to outboard end of lock, lowering water to sea-level, opening gates, and towing ship beyond lock gates, will require not over two hours.

Ship and trucks are hauled into locks and handled therein by means of electrically operated locomotives running on gear tracks located on lock walls. Gates and centrifugal pumps are also electrically operated.

Wet Docks—The waterfront is provided with over 6,000 lineal feet of wet docking space.

Production Departments—The departments for producing sub-assemblies are located along the production line. Some of these including the bow assembly, the stern assembly and the super-structure assembly departments, are equipped with their own sub-production lines. The locations of these

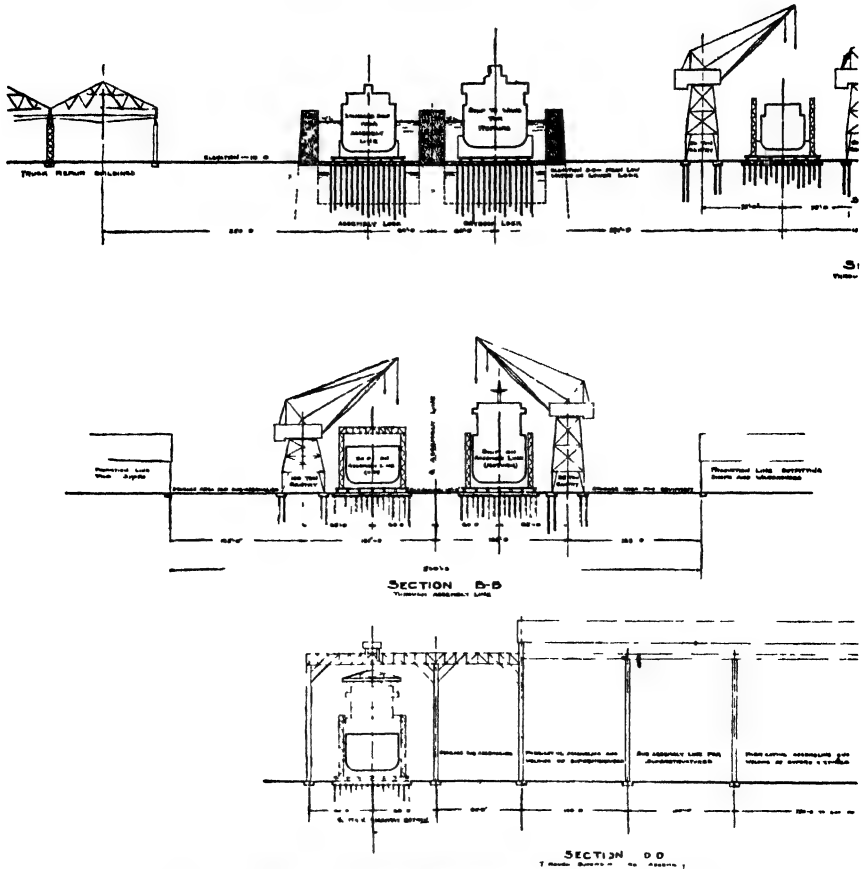
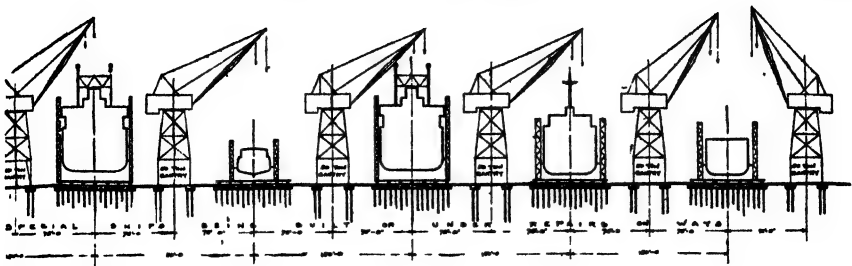
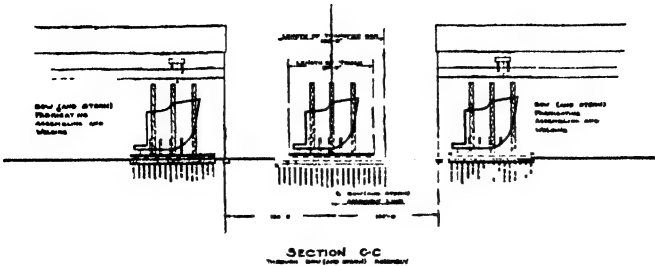



Fig. 2. Sections through shipyard.

departments will be made plain by referring to the accompanying drawings. The size of each department is such as to provide for storage of steel plates, shapes, and other raw materials and equipment, the fabrication of these raw materials into the part or parts desired and the storage of sufficient quantities of cut and formed plates and shapes and finished assemblies so that no bottlenecks will occur in the operation of the departments.

It will be noted that the ships are assembled in relatively large pieces. The keel reaches the production line in one piece. The entire bow assembly is in one piece as is also the stern assembly. These two assemblies are not handled by cranes in their completed state but are each built directly upon one of the 70 feet by 80 feet trucks. When each of these assemblies is completed, it joins the main assembly line, the bow just forward of three trucks carrying the keel and the stern just abaft. These five trucks are then coupled together so as to carry the entire ship.

Forming—Hull and super-structure plating, where curved, will be cold formed and cut to shape in hydraulic presses over metal forms. Forming and cutting presses will be provided in each department where this work is to be done. Presses for hull plating will be equipped with platens 12 feet wide by 40 feet long.

Double Bottoms—The double bottoms are fabricated into sections 70 feet to 80 feet long depending upon the size of the ship and wide enough to extend from the keel to the framing members of either side. Each half section of double bottom is held in place on the production line by appropriate fixtures, where it is welded to the keel structure. It should be noted that the double bottom sections are complete with shell plating and tank-top plating.

Sides—The sides are fabricated in lengths up to 100 feet and are complete with framing, web frames, stringers and outside plating. They are placed in position on the production line, held in place by a system of fixtures, and are welded to double bottom assemblies.

Bulkheads—Each bulkhead is fabricated into a complete structure including watertight doors and frames, all stiffeners, etc. They are lowered into the ship where they are securely held in place by the system of templates mentioned while being welded.

Stanchions and Girders—Stanchions and girders for supporting decks are fabricated in the same manner, lowered into holds and welded in place.

Decks—Deck assemblies are provided in lengths up to 100 feet and are fabricated with deck beams, hatch openings, combings, scuppers, etc. They

are likewise located and held by the system of fixtures and welded to the structure on the assembly line.

Hatch covers and hawse pipes are assembled and installed in a similar manner.

Powering of Ships—The ships are to be powered by Diesel engines each equipped with its own self contained auxiliaries. The selection of Diesel engine power is not a question of economics, but is brought about entirely by the necessity of obtaining maximum installation speed on the assembly line. A complete Diesel engine plant of ample capacity for producing all main and auxiliary engines required for these ships is part of the plant, thus eliminating one major bottleneck to be found in all shipyards at the present time. These Diesel engines may be of any type and make desired by the Commission. They will be manufactured under a license agreement to be made with the present manufacturer.

Upon completion and testing, main and auxiliary engines will be moved from the engine production plant to the main and auxiliary engine departments adjacent to the production line, where they will be accurately mounted upon steel foundations upon which they will permanently operate in the ship. Sufficient space in these departments will be provided so that each engine will undergo a run-in period of 30 days before final assembly in the ship, after completion of which it will be lifted into the engine room where it will be rapidly lined up with propeller shafting in accordance with a prearranged system.

Auxiliary machinery, such as various pumps, heat exchangers, etc., which cannot be mounted with the main engine, together with the necessary piping all cut to exact length and bent to exact shapes will be provided from the last departments on the upside of the production line.

Superstructures—From this point the ship moves onto the upper transfer table and under normal operation is transferred to the return side of the production line where the first operation consists of the installation of the midships and aft superstructures. Each of these superstructures is assembled in one piece (except in the case of ships of maximum size where the weight would be too great. In such cases the superstructure would be fabricated in two pieces). These superstructures are taken from the production department sub-assembly line and hoisted into position on the ship by means of a 300 ton overhead travelling crane.

Additional Departments—Continuing along the return run of the production line, the ship is then provided in order with stacks and boilers; machine shop and crane equipment, ladders, gratings and railings; masts, booms and rigging; tail shafts and propellers, rudders and steering gear; switchboard, batteries and wiring; concrete ballast; non-conducting covering; lubricating oil equipment; winches and chocks; bits and capstans; ventilating equipment and ducts; plumbing; port lights and windows; lighting, wiring and fixtures; controls and instruments; wireless equipment; interconnecting and marine telephone systems; engine room telegraph system; navigation equipment and search lights; anchors and chains; laundry and hospital equipment; deck sheathing; fore and aft armament; joiner work; galley equipment; life rafts and boats; davits and operating mechanism; cargo lines and blocks; fire-fighting equipment; lubricating oil and grease; furniture; bosum's stores; carpets and drapes; linen and blankets; galley supplies, silverware, glassware, and dishes; and miscellaneous stores.

Painting—Each ship has three coats of paint before launching. One coat of paint constitutes the final operation in each of the fabricating depart-

ments. After each section is welded in place on the ship, the welded joints and portions of the metal adjacent thereto are painted. These operations constitute the first coat. There are two paint shops located at convenient points on the return production line. Each of these paint shops provides one additional coat of paint during the construction period.

Handling and Erection—Necessary overhead travelling cranes are provided in each department and are of required capacity for handling the completed sub-assemblies in each case. There are a total of 300 cranes provided for all departments. On the production line, the upper take-off ways, the lower take-off ways, the shipbuilding ways, and along the docks, revolving gantries are used. Special 100 ton gantries are required for the heavier assemblies on the "up" production line.

The remaining gantries are of 50 tons and 35 tons capacity as required. It should be noted that no cutting or fitting whatsoever is done on the assembly line. Each sub-assembly is produced by precision methods and in accordance with rigid standards on a system of fixtures provided for the purpose in each department.

Welding—Sub-assemblies are completely welded to ship structure on production line. No riveting whatsoever is used.

Every possible precaution is to be taken against warping and distortion due to locked-up stresses. These precautions will include carefully simplified designs for equalizing stresses as far as possible; the use of an improved welding technique; adequate water cooling of all members being welded so as to restrict heated portions of metal to minimum areas; the use of small electrodes; the use of reduced voltages; a carefully worked out sequence of welding; back welding; and reduced welding speeds. Careful studies and research have shown that by the use of these methods, distortions can be practically eliminated but at the expense of a somewhat higher welding cost per foot. But inasmuch as this higher cost of welding per lineal foot is usually more than overcome by the high cost of necessary flame straightening where sloppy welding methods are employed, the net additional cost, if any, is insignificant. It is therefore felt that the attainment of fair hull lines and superstructure lines without distortion is worth far more than any slight additional cost which may be involved.

Inspection—Rigid inspection is a necessary part of a plant of this type. Each operation is thoroughly inspected in the various departments and on the production line. Any part or any sub-assembly not up to standard must be rejected before it reaches the assembly line. Work on the assembly line must proceed under the most rigid system of inspection. Tolerances in sub-assemblies can be held to $1/32$ inch.

Fabricating Shop—Passing now to the facilities for servicing the shipways, it will be noted, that a large fabricating shop is provided for supplying fabricated parts for ships being built in the conventional manner on any of the 19 shipbuilding ways. The second floor over the fabricating shop is to be utilized as a mold loft.

Steel Foundry and Steel Scrap—The space between the fabricating shop and foundry is to be utilized for the storage of steel scrap from the various departments of the plant. In most shipyards the steel scrap, which represents a large percentage of the total steel used in ship construction, is wasted or disposed of to scrap dealers at an extremely low price per ton. Sometimes this price hardly justifies the cost of cutting the scrap into sizes and shapes required. In the proposed plant all of this steel scrap will be used in a large foundry designed and equipped to produce steel, iron, brass and

aluminum castings. The large steel castings required such as for anchors, hawse pipes, stern frames, bits, etc., will consume a large portion of the scrap. The remainder will be required for the smaller castings needed.

In a plant of this size, where the output will amount to one complete ship per day, foundry operation becomes necessary not for economic reasons but to help in eliminating other bottlenecks now present in all shipyards, viz.: steel castings of the types mentioned and necessary gear and gear casings all of which will be made in the proposed plant.

Woodworking Shop—The two story wood working shop will be of ample capacity for the production and storage of patterns, joiner work, deck sheathing, etc.

Machine Shop—A well equipped shop will provide all necessary finished and machined parts except those for the Diesel engines which will be machined in the Diesel engine shop proper.

Forge Shop—The forge shop will provide all forgings necessary.

Pipe Shop—The pipe shop will provide the piping departments at the upper end of the production line with the necessary flanged and screwed piping accurately cut, bent and finished to size and shape. It will also supply piping for ship construction on the shipbuilding ways.

Tool Rooms—The central tool room will occupy its own building. The management of this tool room will be responsible for all small tools and equipment used throughout the plant. It will have under its jurisdiction sub-tool rooms located throughout the plant at convenient points.

Riggers' Shop—The riggers' shop will supply the necessary fitted rigging with clips, rope thimbles, turnbuckles, shackles, eye bolts, etc., for rapid assembly on the production line. It will also furnish the same items for ships being built or repaired at the shipbuilding ways or at the wet docks.

Sheet Metal Shop—The sheet metal shop will produce all sheet metal parts to templates for rapid assembly on the production line. It also will be equipped to produce any special sheet metal work required for any ship being built or repaired at the shipbuilding ways or at the wet docks.

Dock Service Buildings—Four dock warehouses are provided for servicing wet docks and shipbuilding ways.

Yard Equipment—The necessary yard equipment is to be provided consisting of Diesel locomotives and locomotive cranes, gondola and flat cars, stake body, dump and pick-up trucks, automotive equipment, caterpillar cranes, truck cranes, fire engines, hose and ladder carts, ambulances and tug boats.

Power Station—A power plant having a rated capacity of 37,500 K.W. is located, as shown, together with the necessary fuel oil storage tanks.

Miscellaneous Buildings, Etc.—Garage buildings are provided for office cars and for trucks and other automotive equipment. Wash and locker rooms are installed adjacent to gates. The central hospital is to be located in the area shown and first aid stations are to be located at convenient points throughout the plant.

The plan calls for a safety department building, police department building, a fire department building and an employment office all located at convenient points.

A separate maintenance plant for mechanical and electrical equipment will likewise be required as well as a main office building for administrative and executive officers and for the office force.

A restaurant building will be installed together with canteens located at convenient points throughout the plant where hot meals can be served

to the workers. A parking space sufficient for all employees as well as for visitors to the plant will be located on either side of the property as shown on the plans. Numbered gates and time clocks will be located along each parking lot so as to give ready admission for workers to that portion of the plant where they are employed.

The plant will be provided with the necessary trackage to accommodate large quantities of raw materials daily required for every department of the plant, and for the interchange of equipment and materials between departments and shops. Hard surfaced roads will also connect to various portions of the plant so that all buildings will be accessible both to rail and road equipment.

The entire plant will be fenced with ten foot wire mesh fencing as indicated on the plans.

IV, Capacity of Plant—When this plant was laid out, it was intended to have a capacity of approximately 1,500,000 dead-weight tons of cargo carriers per year working one shift of eight hours per day. The actual yearly tonnage output will vary over a considerable range depending upon the specifications of the ship to be produced and the number of shifts per day worked. Under war conditions it is to be taken for granted that the plant would operate continuously and the following figures are therefore based on three shifts per day.

It should be realized that the predetermination of the actual yearly output is a somewhat difficult matter. While the man hours required for each operation are fairly well established under usual conditions, the gains in efficiency due to bringing the work to the man and to specializing in repetitive operations cannot be accurately forecast. This has resulted in the assignment of space and labor for each operation undoubtedly in excess of actual requirements, especially after the workmen have been thoroughly trained in their several functions.

Typical Ship—In order to determine the annual output of the plant as nearly as possible, a typical ship of one of the smaller sizes was designed. This ship was kept as simple in design as practicable to facilitate production. The characteristics of the ship selected are as follows:

Length over all	375′	Draft	20′
Length on W.L.	350′	Block Co-efficient	75%
Beam	50′	Displacement, tons	7,500

Assuming a speed of 16 knots, slightly less than 4,800 shaft horsepower, are required. Two 2,400-horsepower Diesel engines were selected operating at 750 revolutions per minute with three to one gear reduction turning twin propellers at 250 revolutions per minute. Engines are located aft. Each engine drives a 200 kilowatt generator, in addition to which, one 250 kilowatt Diesel engine driven auxiliary set is provided for port use. Auxiliaries not included with main engines are installed on one flat and a small machine shop with crane on another flat.

The ship is of two deck construction divided into four holds and tween decks and is provided with double bottoms of conventional design. Two superstructures are provided, one amidships for officers quarters, wheel house, navigating bridge, etc., and one aft for petty officers, crew, galley, etc. Fuel capacity is provided sufficient for a radius of action of 10,000 miles.

The calculated weight distribution of the vessel is as follows:

Hull and machinery (light weight) 4,636,000 lbs.	2,070 tons
Fuel	600 tons
Water	100 tons
Crew and stores	25 tons
Cargo	4,705 tons
Total dead weight	5,430 tons
Displacement	7,500 tons

Rate of Production on Line—Each ship is mounted upon five trucks and travels on the production line at an average rate of approximately one foot per minute. At this rate, one ship per shift or three ships per day would be completed and launched.

Allowing for the time required for truck, saddles, fixtures and keel assemblies, the time consumed in adding bow and stern assemblies and their trucks, the time required on the production line proper, the time required in the upper transfer table and the time required for launching, each ship would be in course of construction for a total of 288 hours or 12 days.

Ample labor has been assigned to the assembly line to complete the ship from sub-assemblies produced and from equipment stored in the various departments in a total of 10 days of 24 hours each. This leaves a factor of safety of 2 days in the estimated time of completion of each ship.

The various departments are proportioned and each is assigned sufficient man power so that all sub-assemblies for one ship are produced at the required rate, that is, three complete sets per day of 24 hours. This high rate of production accounts for the relatively immense size of the sub-assembly departments as compared with conventional practice.

Number of Ships Under Construction—The number of ships under construction on the production line at one time totals 28. It is possible to add 6 ships on the upper take-off ways, 7 ships on the lower take-off ways and 6 ships on the shipbuilding ways, making a possible total of 47 ships. In other words, the number of ships being constructed at any one time in this plant when operating at rated schedule will vary from a minimum of 28 to a maximum of 47.

Yearly Tonnage Output—From the above data the maximum estimated output of cargo carriers of the design indicated in terms of dead weight tonnage is as follows:

From production line—3 ships per day or 1080 ships per year of 360 days @ 5430 tons	5,864,400
From 19 shipways—76 ships per year @ 5430 tons	412,680
Total yearly dead weight tonnage	6,277,080

It seems safe to conclude that the proposed plant will have a capacity of not less than 6,000,000 dead weight tons of shipping per year. In a plant of this type, with fixed space and facilities and a fixed number of hours per day, the production variable is reduced to the labor supply. The rate of production increases with the quantity of trained labor supplied until a certain maximum is reached. Beyond this maximum, additional labor would be crowded into inadequate space resulting in interference and loss of efficiency. At the capacity estimated above, ample room has been provided for all employees.

The other variable is the design of the ship being produced. It can be

shown, for instance, that the rate of production in dead weight tons increases as the size of the ship is increased up to the maximum size producible in the plant. Likewise, the rate of production will increase in proportion to the simplicity of the design and as the speed and power decrease. For example, the yearly tonnage output of the plant when building Liberty ships—the so-called "ugly ducklings"—with their simplified design and slow speed would be greater than with the better designed and equipped and higher speed ships described.

Comparative Output—To equal the yearly output of the proposed production plant, (1156 ships per year) a conventional plant would require 290 shipways and 150 outfitting docks assuming 60 days on the ways and 30 days outfitting for each ship. This speed of production is possible although unlikely as an average. It would require the best kind of organization and the most modern prefabrication methods. However, this rate has been assumed for conventional ways both in the proposed and in the conventional type of plant. It should be noted that 290 ways is almost exactly equal to that part of the total present shipbuilding capacity of the nation engaged in the production of merchant vessels.

If larger, simpler, slower ships were built (such as Liberty ships) fewer shipways would be required for a yearly output of 6,000,000 dead weight tons, but the output of the proposed production plant would also be substantially increased.

V, **Weights of Structures**—An interesting feature of the plant as designed has to do with the total weights and the equivalent specific weights which must be supported and moved. The following figures are presented covering these points. All figures are based upon the typical ship described hereinbefore:

Weight of ship	4,636,000 lbs.
Weight of trucks	1,883,750 lbs.
Weight of supporting saddles	624,000 lbs.
Weight of all fixtures in place	1,250,000 lbs.
Total weight of any one structure	8,393,750 lbs.

The weight to be supported by the trucks (omitting the weight of the trucks themselves) amounts of 6,510,000 pounds. The trucks for the designed ship will have an area of 28,000 square feet so that the weight to be supported on the trucks per square foot amounts to 233 pounds. This presents no mechanical problems as weights of several times this amount may be successfully handled at the slow straight line speeds required.

It can likewise be shown that the total weight on each wheel amounts to 13.81 short tons per wheel. This likewise presents no mechanical problem.

There are two bearing boxes provided for each wheel. The bearings are 12 inches in diameter by 10 inches in length giving a projected area of 120 square inches per bearing or 240 square inches per wheel. The weight to be carried per projected square inch of bearing surface is, therefore, 115 pounds.

The weights to be carried by the transfer tables, wheels and bearings are even more conservative because of the greater areas involved. As an example, the total weight on the transfer table is 161 pounds per square foot of table surface, the weight on the wheels amounts to only 7½ short tons per wheel, and the weight on the axle bearings amounts to only 62 pounds per square inch of projected bearing area.

VI, Estimated Investment—Several factors influencing the cost of the plant are not shown at present because of the fact that the site has not been selected. In preparing an estimate of cost it is necessary, therefore, to assume unfavorable conditions. In the following figures, such items as piling and foundation conditions, extent of required dredging, clearing and grading of site, etc., have been assumed to be unusually severe. The amount of land required to get the necessary size and shape of property is unknown as is the actual cost of the land. It is possible, therefore, that the actual conditions to be encountered at the site finally selected may not necessitate all of the work covered by the estimate and that the land itself may be obtainable at a much lower cost in which event a reduction in actual cost is to be expected.

An abridged estimate of cost follows:

	Item	Cost
(1)	Plant site and yard improvements	$ 20,549,000
(2)	Buildings	52,746,250
(3)	Cranes	7,890,000
(4)	Machinery and equipment (production departments)	2,453,500
(5)	Machinery and equipment (shops)	9,450,000
(6)	Yard equipment	2,827,500
(7)	Production line equipment	10,090,000
(8)	Miscellaneous machinery and equipment	3,992,500
(9)	Forms, templates and fixtures	6,550,000
(10)	Welding equipment	2,965,000
(11)	Utilities	5,425,000
	Sub-total	$124,938,750
	Engineering services (5%)	6,246,935
		$131,185,685
	Administrative, office and miscellaneous expense during construction	2,000,000
	Diesel engine development prior to production	750,000
	Training of superintendents, foremen and leadermen prior to production	1,000,000
	Operation of the shipway prior to production (labor and materials)	1,500,000
	Design and development of standard ship	250,000
	Total estimated cost	$136,685,685
	Contingencies (about 10%)	13,314,315
	Grand total	$150,000,000

VII, Cost of Production—In order to arrive at a relative figure showing cost of production both in the proposed plant and in an ordinary shipyard, the typical ship described in Part V has been used as a basis for the reason that preliminary designs are available for that particular ship.

Fixed Charges—Fixed charges have been assumed at 33⅓% of plant investment in all cases. This is made up of interest 5%, depreciation 20%, maintenance 5%, and taxes and insurance 3⅓%. In the case of the conventional yard, the investment for ways, outfitting docks, shops, ware-

houses, yard improvements and miscellaneous buildings and equipment has been taken at $1,500,000 per way; and the output at four completed and outfitted ships per way per year. This calls for 290 shipways (allowing for only one spare) in order to produce the 1156 ships yearly.

On this basis, the annual fixed charges will amount to $50,000,000 per year or $43,253 per ship for the proposed plant; and $500,000 per shipway or $125,000 per ship for the conventional shipyard.

Overhead—Overhead includes administrative and executive expense, office expense, stationery and supplies, rent, telegraph and telephone, mail, heat, light, traveling and miscellaneous expenses. For the proposed plant this expense has been based upon a detailed analysis of the requirements and includes salaries for an office force of 400 employes. The total overhead amounts approximately to $3,500,000 per year and therefore to $3,030 per ship on the basis of an output of 1156 ships per year.

In the conventional shipyard the overhead would vary over a wide range with the size of the yard. For purposes of comparison, a yard consisting of ten shipways, seven outfitting docks, and the required shops, warehouses, etc. has been assumed as a fair representative plant. Such a plant would call roughly on an executive and office personnel of 200 employes. The total overhead should be not less than $1,000,000 per year. On the basis of an output of 40 completed and outfitted ships per year, the overhead would amount to $25,000 per ship.

Direct Materials—Direct materials amount to about the same for welded ships regardless of the method of manufacture, but for riveted ships the direct materials are slightly greater because of the greater weight of the hull structure. Indirect hull materials and supplies, on the other hand, are much less in the production plant. This results from the standardization of the ship, the large number produced from the same design, the better utilization of scrap and the greatly reduced power, oxygen and acetylene consumption per ship. The estimated value of direct hull materials is $300,000 for riveted ships and $270,000 for welded ships.

Indirect Hull Materials and Supplies—A large saving per ship will be made here by reason of reduced power and acetylene consumption, use of steel scrap, and standarization of ship and processes. The estimated figures are:

for conventional riveted ship..$100,000
for conventional welded ship.. 90,000
for proposed plant.. 50,000

Direct Machinery—There will be a decided saving in cost of direct machinery in favor of the production plant, as this plant will make a large part of its machinery and equipment including main and auxiliary engines, gears, forgings, steel and grey iron castings, brass and aluminum castings, etc. The plant should be designed to produce whatever equipment will be required in sufficient quantities to effect operating economies. In this way, there will be eliminated a large part of the machinery suppliers' overhead and profit. Incidentally, this plan will eliminate some of the principal bottlenecks encountered in present day shipyards. The estimated costs are $200,000 for the conventionally built ship and $100,000 for the production built ship.

Indirect Machinery—Here a small saving per ship will be made in favor of the proposed plant. The approximate figures are—

for conventional shipyard..$25,000
for proposed plant 15,000

Labor—The biggest saving will naturally consist of the saving in labor per ship, both direct and indirect.

The estimated personnel for the entire production plant, both direct and indirect (excepting the administrative, executive and main office force) is as follows:—

	1st shift	2nd shift	3rd shift
Production line and departments	29,960	27,060	27,060
General shops	6,964	5,360	5,360
Diesel engine shops	2,844	2,644	2,644
Cost department	300	300	300
Totals	40,068	35,364	35,364

This represents a total plant payroll of 110,796. It should be noted that this number includes the necessary personnel for operating the production lines proper, all supplying production departments, the general shops, foundries, Diesel engine shops, all shipways, locks, power stations, yard equipment and all necessary miscellaneous labor. Assuming an average wage rate of $1.00 per hour the daily payroll will amount to $886,368 per day, or $277,000 per ship. It should be noted that this estimate covers both direct and indirect labor.

For the conventional yard, the direct labor for the riveted ship is estimated at $400,000 per ship, and the indirect labor at $100,000. For the welded ship direct labor is reduced to $388,000 and indirect labor to $90,000.

Total Cost—Recapitulating the above the following figures showing total estimated costs have been determined:

(A) Cost of production per ship for a conventionally built ship of riveted construction.

(B) Cost of production per ship for a conventionally built ship of welded construction.

(C) Cost of production per ship for a welded standardized ship built in the proposed production plant.

	A	B	C
Fixed charges	$ 125,000	$ 125,000	$ 43,253
Company overhead	25,000	25,000	3,030
Direct hull materials	300,000	270,000	270,000
Indirect hull materials and supplies	100,000	90,000	50,000
Direct machinery	200,000	200,000	100,000
Indirect machinery	25,000	25,000	15,000
Direct labor	400,000	388,000	277,000
Indirect labor	100,000	90,000	
Total estimated cost	$1,275,000	$1,213,000	$758,283

Saving—This tabulation shows a saving per ship in favor of the production plant of $454,717 or about 37.5% of present costs. If the conventional ways in the proposed plant were not used, the relative saving would be greater.

The estimated yearly saving is equivalent to 1156 ships @ $454,717 or $525,652,852. In other words, the production plant would pay for its entire cost in savings alone in less than four months operation.

VIII, Time Required for Construction of Plant—Under present conditions, the time required to complete the plant would be as follows:—

(1)	Plant site and yard improvements complete in	6	months
(2)	Buildings erected in	8	"
(3)	Cranes erected in	8	"
(4)	Production department equipment	8	"
(5)	Shop equipment	16	"
(6)	Yard equipment	4	"
(7)	Production line equipment	5	"
(8)	Miscellaneous equipment	16	"
(9)	Forms, templates and fixtures	6	"
(10)	Welding equipment	8	"
(11)	Utilities	9	"

It will be noted from the above that the "bottlenecks" from a construction standpoint are shop equipment and miscellaneous equipment.

The shop equipment causing the delay is that required for the Diesel engine shops. To overcome this potential delay in starting, it is proposed to contract with outside suppliers for Diesel engines for the first six months of operation of the shops. There should be no difficulty in this because the first engines could be ordered a year ahead of required delivery, so that actual deliveries would be made from 12 to 18 months after date of order. This can be done. In the meantime, the necessary Diesel engine development work would be done and the plant placed in condition to operate as soon as the necessary tools and equipment were delivered.

Under miscellaneous equipment, the delayed time for completion is due to the three 12,500 kilowatt steam turbines for the power station. All other equipment can be shipped promptly. This means that in selecting the site for the plant due consideration must be given to the power developing capacity, distributing facilities and existing connected loads of the surrounding region. It is entirely feasible to select a site where the required power requirements can be supplied from an outside source until such time as the power plant shall have been completed.

There is no reason why the proposed shipbuilding plant cannot be in operation within twelve months from date of approval and possibly somewhat sooner in spite of the fact that probably delays in shipment of certain machine tools and steam turbines may delay the final completion of the plant for six months beyond the date of starting.

Chapter III—Small Boats Arc Welded

By William Atkin,

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William Atkin

Subject Matter: During the last two years, increasing interest has been shown in small boats constructed of metal, the resistance of this type of construction to pounding on a rocky shore during a storm being noted. While the weight of the steel hull is about the same as wood, the former will not leak if properly welded. Various designs of small craft are briefly described, the author commenting on the erroneous tendency of builders to follow traditional lines, instead of designing especially for steel. Boats of the type described are best built upside down, the writer states and proceeds to give detailed instructions for fabrication.

With all too few exceptions, small yachts and boats have always been built from wood and most yachtsmen, being conservative, are not easily influenced by the many excellent aspects of metallic hulls.

However, during the last two years an increasing number of inquiries have come to my office in connection with a proper design for a small boat to be built from metal, welded metal, galvanized iron, steel, bronze, and aluminum.

Most of my clients are amateur boat builders. In recent years with the production of inexpensive arc welding outfits, the urge has come to build from wooden boat construction plans using metal in large pieces in place of the thousands of pieces of wood and fastenings that enter into the building of wooden craft.

One of these amateur builders, Mr. W. I. Nichol, Saugus, Mass., has built two small boats adapted from wooden construction. One an 18-foot V-bottom auxiliary designed by the late C. D. Mower, the other a 23-foot double-end V-bottom runabout from my design. For both these Mr. Nichols has great praise. Of the latter, he writes that in the hurricane of September, 1938, his galvanized Armco iron arc welded runabout, "Needle", was washed ashore before the great wind and tremendous sea, grounding among a forest of jagged boulders and small rocks making up the beach. Excepting for dents and scratched off paint the boat was undamaged structurally. Its motor and equipment were ruined with salt water corrosion. Shaft, propeller, strut and rudder were badly bent. Within a week, the iron-hulled "Needle" was about its tasks again, little worse for her violent experience. Every other of the dozens of small wooden boats that were washed ashore in the locality were smashed into kindling wood, and total losses.

It is interesting to note that Mr. Nichol's runabout was built from galvanized iron, the decks approximately $\frac{1}{16}$-inch thick; sides and bottom plating approximately $\frac{1}{10}$-inch thick. There are no frames, floor timbers, stem, stern, or keel in the construction. Deck beams are the only framing used and these are very light.

When completed and with same motor and equipment specified for the wooden hull, the little boat rested exactly on her designed water line indicating the construction in steel came to exactly the same weight as construction in wood. The boat also made the speed specified for the wooden hull, which is of considerable interest.

A metal hull will not leak if arc welded, and cannot sink if fitted with floatation tanks or water tight compartments. These seem priceless advantages for the metal welded hull.

How long will a steel hull last plated with sheets less than 1/8-inch thickness? Given reasonable care, just as long as a wooden hull of similar characteristics. I am reminded of this fact often having advised one of my clients not to spend good money on the conversion of a World War I galvanized iron life boat. That will have been 18 years ago. The old life boat is still going. I am afraid I was taking too seriously the advice of conservative contemporaries.

A year or so ago another client, Mr. Wayne Backus, Winniwicee, Washington, asked me to design him a 16-foot V-bottom runabout, the boat to be built in a small welding shop by an amateur builder. This boat was not an adaptation from a conventional wooden design.

The hull was built from six sheets of Armco iron, the bottom and side plating being 12-gauge and the deck and bulkheads 14-gauge. Deck beams, tabs, etc. were made from cuttings from the side and deck plates. Four sheets for the sides and bottom were 24 inches and 36 inches wide respectively, while two sheets for the deck were 36 inches wide. All sheets were 17 feet long. The little boat turned out very well, performed exactly like the more usual wooden types. Like the two hulls built by Mr. Nichol, the 16-foot runabout was built without frames, keel, deadwood, clamps, knees, shelves, floor timbers, etc., parts which are always associated with the construction of wooden hulls.

Early in 1940 I completed a third design for Mr. Nichol, this one a V-bottom auxiliary gaff-headed sloop 18 feet 9 inches over all, 17 feet 6 inches water line, 6 feet beam, and 3 feet draft. The breadth was kept to 6 feet because sheet iron of this width and 20 feet long was available.

The design of the 17-foot 6-inch water line steel cruising sloop, (See Figs. 1, 2, 3 and 4) was made several months ago in anticipation of building the little ship for my own use after the war. Having been in the profession of naval architecture for many years, it seems certain to me that the only way in which "everyman's" boat can be produced is to build it from steel. It is impossible to build wooden hulls inexpensively. There are too many parts to be shaped and handled, and wood is too flexible to handle cheaply in forming the hull of so complicated a form as a boat.

The trouble in the past in building small steel hulls has been that they were put together in the same manner as wooden hulls, and not in the manner of a tank or box. Therefore, with all the customary parts used in old-fashioned boatbuilding nothing was saved in time and the completed hull was entirely too heavy. It is astonishing to me that so many moderate sized welded steel hulls are built today with so many unnecessary parts—positively steeped in tradition both as to form and construction.

My tabloid sailing boat has dimensions as follows: length over all, 19 feet 8 inches; length water line, 17 feet 6 inches; breadth, 7 feet; draft 2 feet 11 inches. The freeboard at the bow is 3 feet 2½ inches; at the lowest point, 2 feet 2 inches; at the stern, 2 feet 4¼ inches. The displacement is 4,100 pounds; sail area, 194.4 square feet; and ballast, all inside, 1,200 pounds.

And, by the way, this is my 490th design since going into business 34 years ago.

If the war does not run too long I expect to put boats of this type and construction on the market in three sizes: 17 feet 6 inches, 22 feet, and 27 feet water line. Arc welding and steel hulls will by then be easy to sell through the impetus given the trade by the thousands of vessels of all sizes and types produced for the winning of the war. Skill in arc welding will be common knowledge to hundreds of thousands of workmen before that glad date is crossed off the calendar.
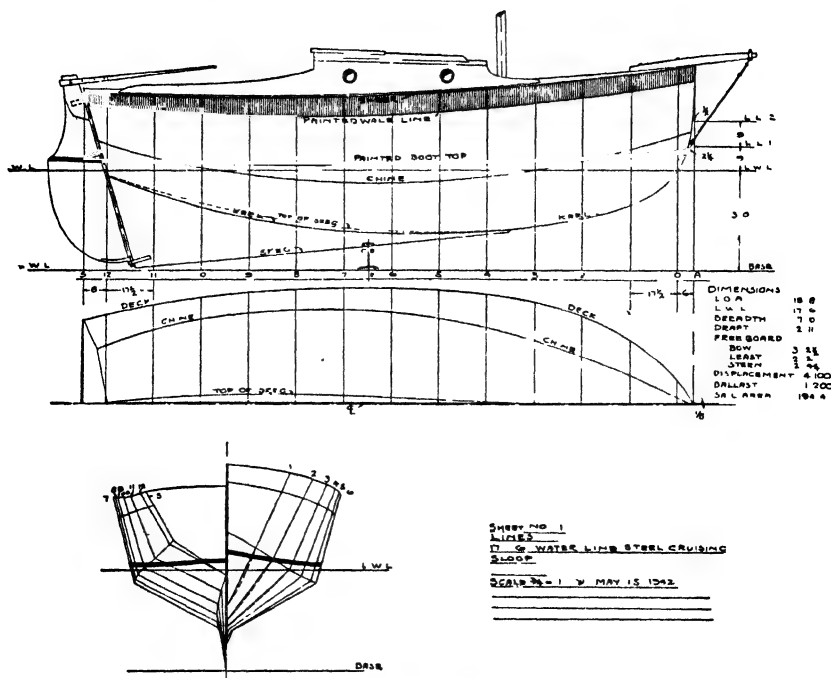
Fig. 1. Lines.

It is difficult for the layman to realize that a hull plated with 12-gauge rolled steel will weigh about the same as a hull planked with three layers diagonally of a total thickness of 1⅛ inches of white oak. And this would be considered exceedingly heavy for a small boat like the subject of this paper. If built of weldwood this thickness floor timbers, stringers etc., would be unnecessary deadwood. But one cannot built a boat with weldwood without stringers, keel, chine pieces, deadwood, and all the parts that make up the hull of a wooden boat. Only the fitting and forming of frames is saved in plywood hulls, and the plywood must be screwed or glued to something to maintain its position and shape. And then, of course, there are thousands of wood screws or copper rivets to be bored for and driven before your wooden hull is completed, a time-consuming job.

Items to be made, handled and fitted in wooden hull of this type and size are: 30 planks. 28 battens. 42 deck planks. 2 pieces canvas with glue and tacks. 1 keel. 3 pieces deadwood with 26 bolts. 3 pieces in stem. 11 pieces in stern. 2 clamps. 2 shelves, each made from two lengths. 3 knees. 24 chine knees. 2 rabbeted chine logs. 48 bolts in keel, stem, stern assembly.

12 floor timbers. 16 butt blocks. 7 doublings. 5 pieces in rudder. 18 deck beams and headers. 6 pieces half round sheer moulding; plus 3,230 fastenings of five different sizes with wooden plugs to cover countersinks over heads, making a grand total hull lumber and fastenings, 3,495 pieces not including boat plugs which will come to at least 1,200 more.

Items to be cut, handled and fitted in arc welded steel hull of similar size and type to above are: 2 pieces 36 inches by 20 feet 12-gauge plate for sides; 2 pieces 40 inches wide by 20 feet long 12-gauge plate for bottom; 2 pieces 36 inches wide by 12 feet long 12-gauge plate for skeg; 2 pieces 40 inches wide by 20 feet long 14-gauge plate for deck; 1 piece 52 inches wide by 10 feet long 12-gauge plate for cockpit bottom and sides; 1 piece 20 inches wide by 6 feet long 12-gauge plate for rudder; 1 piece 36 inches wide by 5 feet long 12-gauge plate for stem; 34 deck beams and headers made from scrap from side plating, 12-gauge plate, 1½ inches and 1-inch respectively; 4 butt plates under center seam in deck; making a total of 48 pieces required.

The above tabulation concerns the hull only with rudder. However the interior fittings and rig in either wood or steel hulls will require about the same materials and time to complete.

If only one hull is considered, it should be built over wooden forms made in the same manner as for wooden boats. Use spruce about 1⅛ inches thick for the forms and brace well both to floor and to each other. If duplication is required in quantities it would be best to build the form from steel plates and shapes. A form must be made for each of the stations shown on the drawing of the lines. And the lines should always be drawn, (or laid down) full size. Too much care cannot be given this part of the work.

Since there is no keel in this type construction the forms should be set up upside down, that is with the deck down. The simplest way to do this is to set up blocking for each station so that the tops of these form the sheer line in an upside down position. Set the blocks at convenient height to work comfortably. Raise the forms sufficiently high from the floor to allow for a strong batten 6 or 8 inches above the line of the sheer. This will give better working room in fitting the plates. Also run battens let in flush, two each side for both bottoms and sides. These will brace the forms. Fasten with wood screws.

It is good practice to saw a piece of ½-inch plywood to the curve of the keel and stem from station 2 forward as a guide or pattern for cutting and fitting the forward ends of the side and bottom plates. This should be placed about 1½ inches abaft the cutwater of the stem; it will be inside the hull when the plating is on.

V bottom models with straight sections are ideal for building with welded steel. One bend only is required of the plating and none will have to be furnace heated and rolled and hammered into place. You will notice there are dotted lines indicating slight convex below the chine at stations 1, 2 and 3. The steel will take this form naturally and the sections will appear to be perfectly straight. This is the way it is intended.

V bottom models are also excellent performers in rough water and equally as fast as round bilge craft, provided, of course, that the design is of correct form for both types.

The topsides of the sailing boat will be made from 12-gauge steel plate. It can be had in a single piece. If butted plates are needed see detail for this joint on the construction-cabin plan. For the amateur builder, it may be well to mention that plating of this thickness must be cut with power shears or with the welding outfit. Shears will be best, I feel, for this particular work.

Fig. 2. Construction and cabin arrangement.

The surest and best way to obtain the exact shape of each plate is to make patterns from hard strong cardboard. Since both sides of the hull must be alike, pattern should be made for one side only. Lay pattern on the plate with colored pencil or scriber. Mark the position of each form. Bore holes for wood screws along the sheer edge of the plate and at the edge of the chine at each mould. Also bore holes about 5 inches apart along the stem approximately 1 inch abaft the cutwater, also at the top and bottom of the stern end of the plate. One-quarter-inch bolts and screws will be inserted in these to hold the side plates in correct position until welded together. Clamps can be used here to advantage also. All the plates will have square edges, tops, bottoms, and ends, no bevels required. In welding, the welding rod will build up a neat rounded bead, entirely filling the seam or joint between the plate edges.

Both halves of the bottom plating will be treated in the same manner and will be made for the same thickness steel plate.

The stern will be made from 12-gauge plate and will be temporarily fastened with screws, bolted and clamped in exact position, then arc welded to the sides and bottom. Leave all edges square in same manner as on sides and bottom plating.

If welding is neatly and properly done it will be best to leave joinings in natural state without grinding or filing smooth. The scale left by the heat will rust much less than bright surface.

Cementing and painting will form a very smooth and fair surface and the beaded corners of chines, cutwater, and at the stern will look business like and neat. It may be well to mention that a steel hull should not be painted with the usual copper anti-fouling compositions used so successfully on wooden hulls, so do not use any paint that contains copper, aluminum or brass. The finest quality red lead in oil is best for priming coat, and apply two thin coats rather than one thick coat slapped on in a hurry, followed by at least four coats of gloss outside yacht paint. Anti-fouling white composition will be best for underwater portions.

Deck beams will be made from 12-gauge plate. Those of the main deck will be 1½ inches deep and will be spaced on every station with one between. The crown of the beams will be 2 inches in a length of 4 feet. The ends of the beams will be arc welded to the inner face of the side plating at the sheer. Hatch headers, cabin house carlines, cockpit floor beams will be of the same dimensions.

Cockpit floor and sides with cabin sides and ends will be made from 12-gauge plate, also cockpit coamings. Floor of cockpit is flat and the beams should extend full across the hull having ends welded to side plating.

The deck will be made from 14-gauge plate. It will be difficult to get plate in this thickness 7 feet wide and so it will be necessary to run seam through the middle line of the deck. Use corner weld for fastening deck to side plating and spot-weld deck from under side to deck beams. Cabin house top will be made the same but the beams here will be 1 inch in depth and set on 12-inch centers.

The sides of the open skeg will be made from 12-gauge plate and formed and fitted to hull as clearly indicated on the plans.

Rudder will be 12-gauge plate. It would be well to fit cheek pieces made from white oak each side the rudder head to give it thickness to support the tiller which will be 1¾ inches thick. Then the side plates on tiller that form the hinge will exactly span the rudder head and form a very solid fitting.

It being impractical to finish the interior in steel plate it will be necessary

Fig. 3. Sail and deck plans.

to weld tabs made from 14-gauge plate to give attachment places for the various wooden members of the joiner work. Through-bolt wood to the tabs wherever possible. Then everything can be removed if it is ever necessary to repaint the interior or chip off scale. But this operation will be a long, long way down the wind if the boat is half way cared for. One half-inch thick weldwood is excellent material for constructing the interior joiner work.

And there we have the hull for a very nice little cruising boat.

Ballast will be cement loaded with scrap pieces of plating.

The cabin is designed for two, and has everything needed for comfortable living and sailing. Provision is made for installation of pump water closet if this is needed. One cannot expect full headroom in a small boat like this and so long as there is full sitting up headroom the cabin will be found to be snug and homelike. And whatever the weather outside, you can be sure the decks and arc welded steel hull will be absolutely watertight at all times. This is a comfort in any type cruising boat.

OFFSET TABLE 17 6 WATERLINE STEEL SLOOP SHEET NO 4

STATION	A	0	1	2	3	4	5	6	7	8	9	10	11	12	S
HEIGHTS															
LWL TO SHEER	3 2¼	3-1	2 10¾	2 8½	2 6¾	2 5⅜	2 4+	2 3¾	2 2½	2 2⅛	2-2	2-2¼	2 2¾	2-3½	2-4+
LWL TO WALE LINE	2 8⅛	2 1⅛	2 4¾	2 2	2 0	1 10⅜	1 8¾	1-7¾	1-7¼	1 7⅛	1-7½	1 8¼	1 9¼	1-10¾	1-11½
BASE TO CHINE		4 0½	3 7¾	3 3¾	3 0	2 9⅜	2-8¼	2-7½	2-7½	2 8¾	2-10⅜	3-1	3-4½	3-8½	
BASE TO KEEL		3 0	1 11⅝	1 6½	1 3¾	1-2⅛	1-1¾	1-1⅛	1-2	1-3⅞	1-7⅝	1 10⅞	2 4	2-10	
BASE TO SKEG						1-1		STRAIGHT					0-1⅞		
GET BASE TO TOP OF SKEG FROM WORK															
HALF BREADTHS															
DECK	0 0⅛	0 8¾	2 11	2 7⅝	3 0¾	3 3⅝	3 5⅛	[illegible]	[illegible]	3 5⅛	3-4	3-2¼	2-11½	2-7⅞	2-5⅜
CHINE		0 2½	0 10⅜	1 5¼	1 10⅜	2-3½	2 6⅜	2 9	2 9⅜	2 9½	2 8½	2 6¼	2 2¼	1-8¾	
TOP OF SKEG						0-1	0-1½	0 2⅜	0 3	0 3⅜	0 3⅜	0-3	0-2	0-0⅜	
BOTTOM OF KEEL	0 0⅛				SAME FOR ENTIRE LENGTH									0-0½	
BOTTOM OF SKEG						0 0⅛		SAME FOR ENTIRE LENGTH						0-0⅛	

DIMENSIONS TO OUTSIDE OF PLATING IN FEET AND INCHES

Fig. 4. Offset table.

The rig is the accepted type today with tall mast, and short foot, altogether proved and accepted as efficient as the rig for a small sailing boat can be.

The time required for building the hull with decks, deck house, cockpit, hatches, companion slides, ballast, toe rails, and rudder of a standard type wooden hull of 4,100 pounds displacement will be very close to four weeks with two experienced boat builders, or approximately 384 hours, provided the materials are first class and proper power tools available. At 80 cents an hour this is $307.00.

First class boat building lumber for the hull as above will cost at retail, $210.00, fastenings, caulking cotton, boat plugs very close to $40.00. Thus, the hull complete, $250, with labor, $547.

The hull completed represents very close to 2/5 ths the cost of the whole outfit, joiner work, fittings, spars, rigging, sails, and painting will bring the complete boat to a figure of $1,365. And this will be a good average price in normal times for a boat builder with a good reputation for good work and materials.

The time required for building an arc welded steel hull of the same displacement and model will be very close to ten days with two experienced steel boat builders and welders, or approximately 160 hours, providing the steel plates were of specified sizes and proper tools were on hand to produce the work. At 80 cents an hour this is $120.

The steel plates for the hull completed to the same point as the wooden hull will cost $136 including welding rod. Electric current will add close

to $20 at local rates. Thus, the arc welded hull complete with labor, would cost $276.

The boat completed then with arc welded steel hull and equipment exactly the same as the wooden boat above will have a cost of $1084, a saving of $271 or slightly less than 20 per cent.

In the plans, the conventional symbols for welding have been omitted as being of little use to the amateur welder, and the professional welder will consider the job a simple straightforward bit of work that can be done blindfolded.

From the above one can see the possibilities of great savings in labor and materials if small simple boats are built from steel arc welded.

Chapter IV—Welded Steel Boat Design

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Subject Matter: Not satisfied that yachts of less than 80 feet in length are necessarily heavy and impracticable when built of steel as compared with wood, author offers the design of a 30-foot cabin cruiser. Principal characteristics, together with necessary calculations and design details, are given. This is followed by an account of the method of fabrication and erection of sub-assemblies. Estimates of weight and cost are made and the improved efficiency, strength, increased safety and greater desirability of welded steel construction are stressed.

The purpose of this paper is to present a yacht design of welded steel construction. The idea was conceived as a result of an argument with another naval architect who contended that yachts of less than 80 feet in length would be heavy and impractical when built of steel as compared with the conventional wooden designs. The author, not convinced by argument and believing that ordinary small boats of welded steel construction would possess many inherent advantages, presents, herewith, some comparisons between wooden and welded construction as applied to a 30 foot cabin cruiser—an average size boat in yachting and considerably below the 80-foot limit which is generally considered the turning point in length above which steel is accepted and below which steel construction has not yet been adopted except in isolated instances.

General Uses—Small boats, including yachts, see service all over the world in every conceivable form and shape. Performing useful work for some, providing a luxury for others, an absolute necessity upon occasion, they all embody problems of design too numerous for detailed elaboration. The soldier at Dunkerque was looking for any boat—the yachtsman at Miami is looking for his boat. English Channel or Biscayne Bay, when a boat is wanted, it is there for a purpose which must be constantly borne in mind during the design stage.

Special Uses—Deep-water boats require excessive ruggedness; fast boats require lightness; cruising boats require comfort; work boats require load capacity—every boat has a purpose and each has its own peculiar qualifications for that purpose. All boats have the basic requirements of stability, seaworthiness, and economy.

The design incorporated herewith, (See accompanying Figs. 1, 2, 3, 4 and 5), is presented as being a fair example of the ordinary small boat employed as a yacht. The average amateur yachtsman has a motor boat of around 30 feet in length, having berthing and living facilities for four persons and capable of cruising two weeks comfortably at a speed of ten knots (twelve miles per hour)—all on a modest initial outlay and involving reasonable upkeep.

Variations in Design—One of the basic points incorporated in the design is the use of one jig from which two models could be constructed; one boat being thirty feet in overall length and the other, by means of a ten foot addition aft, being 40 feet in overall length—the standardization of patterns and parts being a direct economy to both models. Of the ten feet addition in length, six feet is below the water line resulting in a greater speed at the same speed length ratio and four feet is used in extending the overhang of the stern resulting in a more appealing "cruiser stern". The 40-foot model would accommodate six persons and have a top speed of 16 knots (19 miles per hour) using two screws. The engines, shafting, propellers and 75 per cent of the hull would be identical with the 30-foot model.

Principal Characteristics—For purposes of discussion and for comparison with wooden contruction the 30-foot boat of welded steel construction has been chosen. The general characteristics are as follows:

Length overall	30′—0″
Beam, extreme	8′—7″
Draft, service conditions	2′—9″
Displacement, service conditions	15,000#
Speed, economical	6 Knots (7 M.P.H.)
Speed, maximum	10 Knots (12 M.P.H.)
Shaft horsepower, maximum	85
Accommodations	4 persons

Framing—The boat is designed on a semi-longitudinal basis with web frames spaced at intervals from 12 to 18 inches. The form of framing contributes not only to greater lightness of construction but also to ease in attachment of hull plating. The web frame varies from 3-inch x 2-inch tee sections amidships to 2-inch x 1½-inch tee sections at the ends. These tee section webs support longitudinals which are also tee sections which vary from 2-inch x 1½-inch to 1-inch x ¾-inch. This system of web frames and longitudinals supports the structural plating; namely, the bottom, sides and deck of the hull. Light intermediate frames, varying from 1-inch x ¾-inch tee sections to 1-inch x ¼-inch flat bars are spaced between webs where necessary for local stiffening of plating. All the sections have a face plate thickness of 3/16-inch and a web thickness of ⅛-inch. Adequate tripping brackets are provided to insure stability of the web frames and longitudinals. All web frames are tied into the heavy keel plate by deep floors (which are lightened where possible). These floors are 3/16-inch thick.

Thus there is provided an interlacing system of support; the deep web frames support the longitudinal stringers which in turn support lighter intermediate frames—the whole system benig tied into the keel plate and supporting the hull plating in such a manner as to insure the maximum strength and stiffness with the minimum weight.

Plating—The keel plate is ⅜-inch thick, shell and bulkhead plating varies from ¼-inch to 3/16-inch, deck house plating is ⅛-inch thick. Ample margin for possible corrosion is provided.

Due to the small size of the structure, those portions below the chine present a problem. In order to reduce the amount of forced curvature of this plating the entire surface of the hull is designed around conical surfaces. The hull below the chine consists of two conical surfaces and the deck is a cylindrical surface. The vertexes of these cones are located on the body plans. In order to avoid unfairness in the hull plating and undue stress in the structure it is necessary to lay off lines in the loft by geometrical means rather than by the conventional offset method.
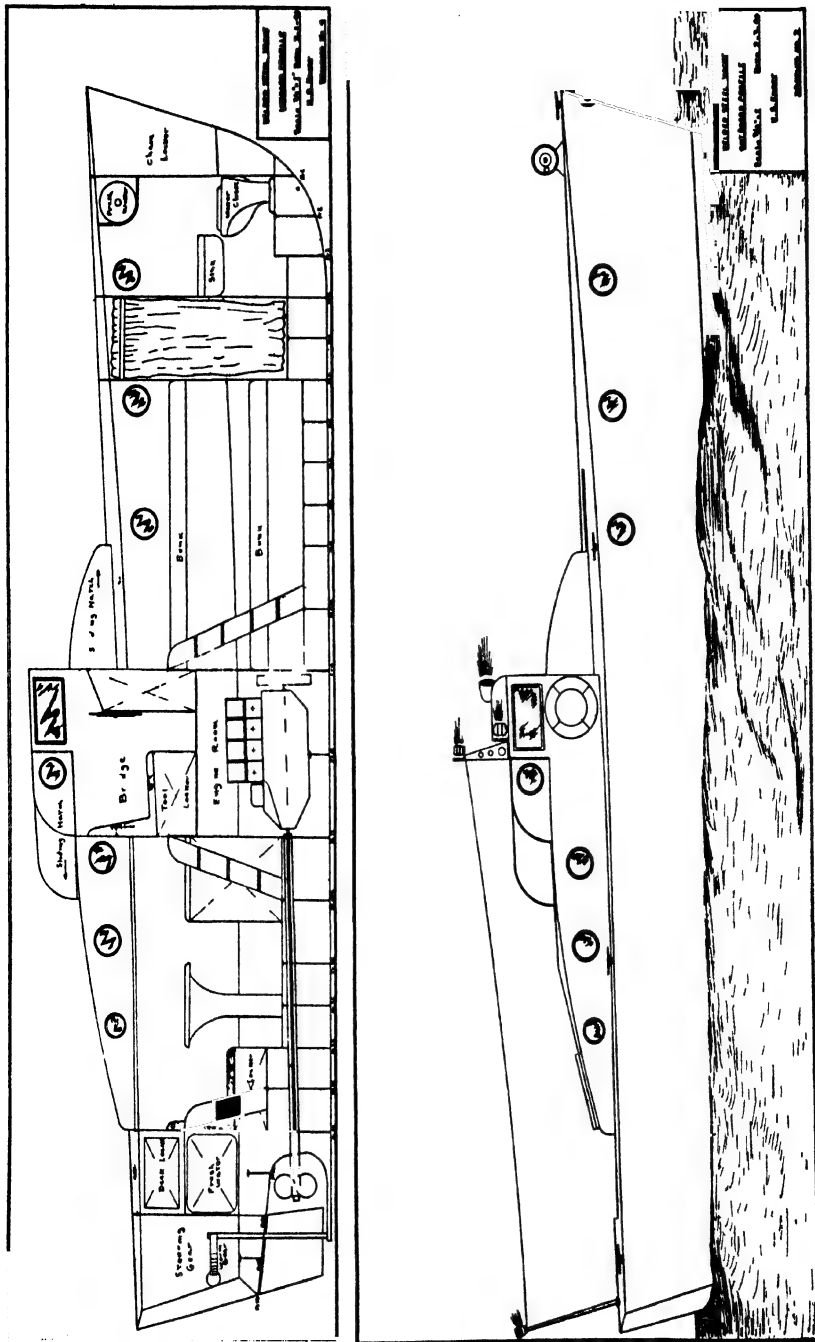
Fig. 1. (above). Outboard profile. Fig. 2. (below). Inboard profile.

All subassemblies such as lower hull, main deck, side framing and plating, bulkheads and deck house are to be sand-blasted, pickled and galvanized after fabrication and just prior to erection of the subassemblies after all miscellaneous welding has been completed. Welding done after galvanizing shall be wire-brushed and painted with zinc chromate priming paint.

All plating used in the construction of the boat is medium steel having a yield point of not less than 60,000 pounds per square inch.

Equipment and Arrangement—The boat is intended to provide comfortable day cruising for four persons and special emphasis is put into extended cruising accommodations for two persons; a combination which would represent the average pre-requisites for such a boat.

Aft of the chain locker is provided a watertight compartment having in it a water closet, lavatory with running fresh water, and adequate space for shelving. In the next compartment aft there are four bunks; two port and two starboard, the upper berths on each side folding down to provide a back rest. There is also provided in this compartment two closets and ample shelving.

Amidships is a watertight compartment, housing the main power plant and auxiliaries. Directly above the engine room is the bridge provided with a sliding cabin top which may be pushed aft to provide standing room when weather conditions permit. For foul weather operation the cabin top is closed and seating arrangements for helmsman and navigator are provided. There is on the port side a chart table with radio under and the binnacle is on the starboard side.

The after cabin is fitted out as a day cabin with transoms and tables, refrigerator, sink, stove and dresser. Special provision of space and lighting is provided here in order to insure comfort.

Throughout, construction is of welded steel-joiner work being of light gauge.

Conditions of Loading—While strength may not appear to be a paramount consideration in small boat construction, there are certain advantages inherent in a steel design that warrant an investigation of this subject.

A welded steel hull is much more readily made watertight than a wooden hull and it is therefore possible to provide a watertight compartmentation of the hull that will insure the buoyancy of the boat even with one compartment flooded.

Also a welded steel hull, being more susceptible to subassembly than a wooden one, involves the question of sufficient strength to permit handling of major subassemblies prior to actual erection.

For purposes of determining the maximum stresses that would be involved in meeting the above situations the following conditions have been investigated: (a), normal condition afloat. (b), afloat with water closet bilged. (c), afloat with forward stateroom bilged. (d), afloat with engine room bilged. (e), afloat with after cabin bilged. (f), grounded at extreme ends of boat. (g), drydocked on four evenly spaced blocks.

Summary of Longitudinal Strength Calculations—An important correlative of compartmentation is stability; upon assuming that a particular compartment has been bilged and therefore imposes an additional load upon the hull as a whole it is also necessary to keep in mind the change in trim and stability. Loss of stability due to a free body of water within the hull is a major problem and can only be met by providing ample initial stability

when the hull form is determined. Local rigidity and ability to maintain watertightness in a bilged condition is also a major consideration.

Results of a loading analysis are summarized as follows:

	Displacement	Draft For'd	Draft Aft	Meta-Centric Height	Bending Moment Foot Lbs.
(a) Normal condition afloat	15000#	2'–9"	2'–9"	22"	4000
(b) Watercloset bilged	17500#	3'–10"	2'–6"	13"	12500
(c) For'd stateroom bilged	27500#	5'–2"	2'–6"	10"	9200
(d) Engine room bilged	19000#	3'–1"	2'–11"	16"	16500
(e) After cabin bilged	22500#	2'–9"	3'–10"	6"	4000
(f) Grounded at frames—#6 & #24				0	40000
(g) Grounded at frame—#15				0	40000
(h) Drydocked at frames—#6, #13, #17 & #24				0	20000

Steel Versus Wooden Hulls—In designing the welded steel hull, no attempt has been made to save weight with relation to a wooden hull of the same form and dimensions. The overall weight of the welded steel boat is the same as that of a duplicate boat of ordinary wood construction.

In comparing strength, it will be found that pound for pound of weight the steel hull is about twenty times as strong as the wooden hull on the basis of longitudinal strength. This fact would be meaningless if it were not for the greater possibilities of mass production, wider application, safety and durability due to welded construction.

The main strength members have already been described; they cannot properly do their work however without the thorough rigidity of plating and local stiffening which is provided by welding. By providing tripping brackets and local light stiffening bars at points where panting of the hull plating or twisting of main structure will normally occur it is possible to provide a hull of uniform rigidity and strength. Welding of these important items is far superior to riveting in necessarily light weight steel and provides an efficiency in strength and ability to suit conditions that cannot be approached in wooden construction. Welding provides a means of putting steel to work where rivets and nails, with their lesser joining efficiency, cannot even be driven.

Fabrication—One of the principal advantages of welded steel construction is the simultaneous fabrication of the many parts that go into the completed job. These individual fabricated parts are then made up into subassemblies. There are listed below the major items which would be prefabricated in quantity before subassembly: (1), keel plate. (2), stem and stern post castings. (3), floors. (4), lower portion of web frames. (5), lower portion of bulkheads. (6), chine and longitudinals. (7), bottom shell plate. (8), deck stringers and beams. (9), deck plating. (10), deck house coaming and stiffeners. (11), upper portions of bulkheads. (12), longitudinal bulkheads. (13), cockpit sides. (14), cabin floors. (15), upper portion of web frames. (16), side shell plating. (17), hatches.

Subassembly—The first major subassembly consists of the bottom made up of keel, stem and sternpost to which are welded the lower portions of bulkheads, web frames and floors. Longitudinals #1, #2, #3 and chine are then welded to the bulkheads, web frames and floors. The bottom shell plating is then fitted, buttstraps fitted and remainder of structural welding

completed. The subassembly is then moved to the skids and the cabin flooring is installed.

The second major subassembly consists of the main deck, made up from deck edge angles, deck beams and deck longitudinals to which the deck plating is fitted and welded. Deck house and hatch coamings are also welded in place and the subassembly is moved to the skids.

The third major subassembly consists of the deck house made up of
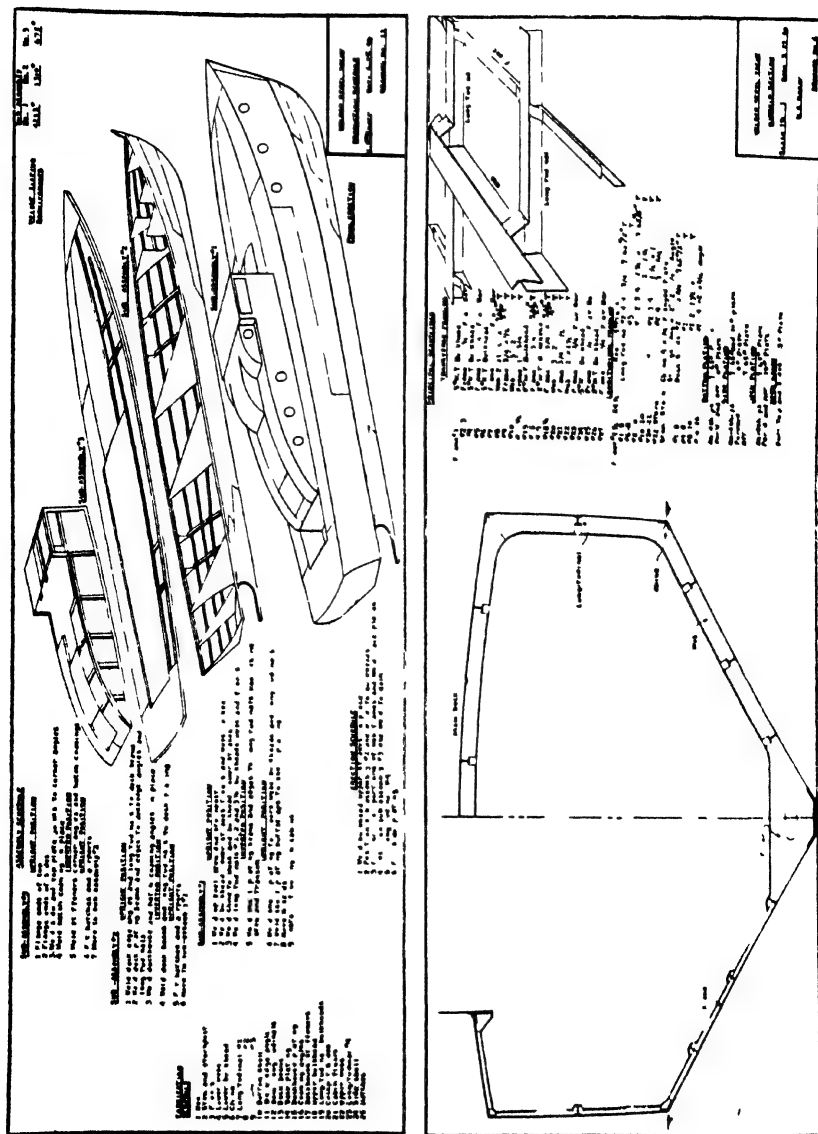
Fig. 3. (above). Midship section. Fig. 5. (below). Production schedule.

framing to which the plating is fitted and welded. Coamings for hatches and airports are installed and this subassembly is then moved to the skids.

All three subassembly operations can be carried on simultaneously on separate sites completely divorced from fabrication work which is of a different nature and involves a different technique. Time and effort are thus conserved in welded construction whereas in wooden construction, fabrication and subassembly are hopelessly intermingled to the disadvantage of each.

Erection—To the skids, where final erection takes place, the subassemblies come for the final fitting.

After locating the bottom structure very carefully on surveyed lines the upper portions of the transverse bulkheads are welded to the bottom portions. The main deck subassembly is then carefully positioned and welded to the transverse bulkheads. The upper portions of the web frames are then fitted to suit, welded to the lower portions and to the main deck beams and the web frame face plates are welded in. The deck house is then positioned over the main deck, fitted into the coaming and welded in place, after the engine has been shipped.

This leaves the structural job virtually complete with the exception of longitudinal #4 and the side shell plating. These two items are purposely omitted until the very last job before launching in order to provide convenient access for work; welding in particular. After the local stiffening jobs have been completed the boat is closed up and ready for launching.

By the use of welding, the work prior to launching (at which time the boat is virtually complete) has been efficiently and simultaneously carried out in six logical sites: (1), fabricating shop. (2), subassembly area for bottom structure. (3), subassembly area for main deck. (4), subassembly area for deck house. (5), erection site. (6), fitting out afloat.

Weight—There is listed below a summary of the estimated weights involved in the construction of the boat.

Item	Weight
Stem casting	300#
Stern casting	392
Keel plate	292
Floors	146
Web frames	203
Transverse bulkheads	1150
Transverse framing	122
Longitudinal framing	445
Shell plating	3539
Deck plating	864
Deck house	650
Weld metal (deposit)	510
Rudder	70
Propeller, shafting, shaft tube and bearings	197
Main engine	1775
Steering gear	50
Interior joiner work	1300
Ladders	100
Doors, hatches, air ports, windows	585
Furniture	790
Galley equipment	120
Mooring equipment	200
Total Weight	13800

Material—There is listed below a summary of the estimated material costs involved in the construction of the boat:

Item	Cost
Castings—medium steel	$110.00
Plate—medium steel	165.00
Shapes—medium steel	50.00
Pipe—medium steel	20.00
Welding electrode	100.00
Bronze bar	45.00
Plumbing fixtures, pipe and tubing	75.00
Radio, electric wiring and fixtures	75.00
Insulation	35.00
Furniture	70.00
Airports and windows	120.00
Power plant	560.00
Steering gear	25.00
Total Direct Material	$1450.00

Labor—There is listed below a summary of the estimated labor cost involved in the construction of the boat:

Item	Cost
Shipfitters	$ 575.00
Welders	380.00
Burners	155.00
Chippers	120.00
Machinists	120.00
Electricians	100.00
Painters	90.00
Shipwright	80.00
Plumber	50.00
Joiner	30.00
Helpers	175.00
Total Direct Material	$1875.00

A small boat of welded steel construction possesses many advantages that are of interest to both the builder and the owner. The major advantages are listed herewith:

(1) Welded steel provides a more efficient method of construction than is possible with wood because it makes possible the simultaneous execution of work at six different sites as compared with two or three with wooden construction. This results in more efficient working methods applied by a greater number of men over a lesser period of time. Welded steel therefore lends itself more naturally to mass production than does wooden construction.

(2) Welded steel widens the field of application of any given design. Due to its greater strength and flexibility as compared with wooden construction it more readily lends itself to minor alterations in construction to suit special requirements of building or operation.

(3) Welded steel construction affords a wider margin of safety than is found in wooden construction due to its resistance and non-susceptibility to fire, its inherent watertightness and its greater strength.

(4) Welded steel construction is more durable than wooden construction which is very susceptible to rotting and marine animal life. Given the proper protection against corrosion and the proper preservation, welded outlast wooden construction.
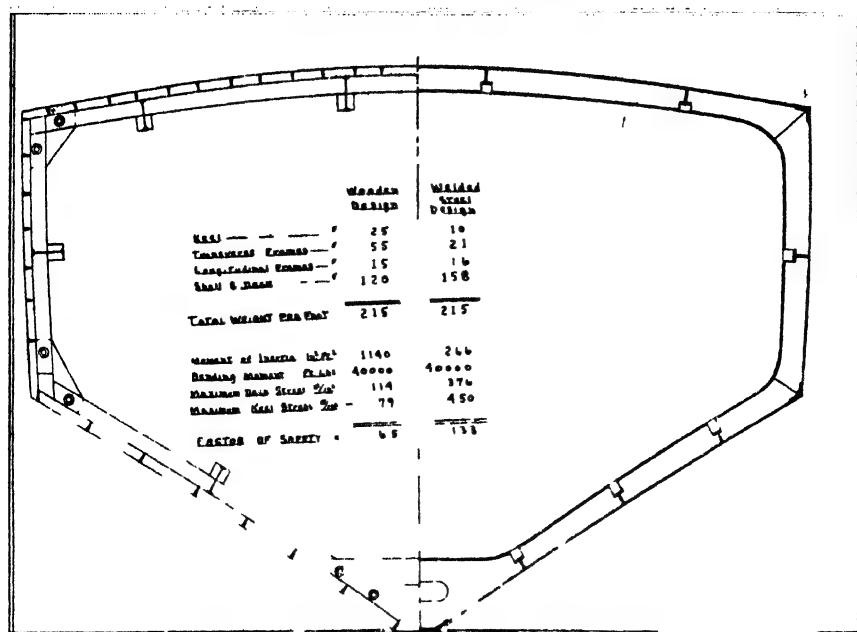
Fig. 4. Comparison welded and wooden design.

A summary of the estimated cost of building small boats of welded steel at the approximate rate of forty boats per year, each boat involving about 2500 man hours is given herewith

	Weight	Material	Labor	Total
Fabrication and layout	....	....	$ 430.00	$ 430.00
Bottom subassembly	4213#	$ 200 00	360.00	560.00
Main deck subassembly	1310#	85.00	140.00	225.00
Deck house subassembly	675#	50 00	150 00	200.00
Final erection	2700#	75.00	270 00	345.00
Machinery installation	2011#	715.00	215.00	930.00
Fitting out	2891#	325.00	310.00	635.00
Fuel, water, and stores	1200#	....	....	....
TOTAL	15000#	$1450.00	$1875.00	$3325.00
ESTIMATED OVERHEAD				550.00
ESTIMATED TOTAL COST TO BUILD				$3875.00

Advantages claimed for welded steel construction as compared with wooden construction assuming the weight and cost of each to be the same: (1), it lends itself more naturally to mass production. (2), it widens the field of application of a given design. (3), it affords a wider margin of safety. (4), it is more durable.

SECTION V
Structural

Chapter I—Welded Airplane Hangar

By VAN RENSSELAER P. SAXE,
Consulting Engineer, Baltimore, Maryland.

Van Rensselaer P. Saxe

Subject Matter: Fabrication and erection of a hangar 131 feet by 244 feet of the truss-and-column type; believed to be the first all welded steel hangar. The riveted design required 282 tons of steel; this welded design required 221 tons. Clips were used for temporary field connections prior to welding. Bottom chord connections of trusses to posts were welded after all steel was erected, so that truss deflections would not bend the columns.

This history of the development of what the author believes to be the first all welded airplane hangar, 131 feet x 244 feet in size, is recited in an effort to show the greater economy, when compared to a riveted structure of this type, designed for ordinary truss spans with which design methods most engineers are familiar and which requires the simple fabricating practices which all shops can do economically with their present welding equipment.

The writer further believes that after our present war effort, there will arise a demand for this type of hangar and that this illustration with its general success, with comments on changes which he could make in another similar design, which would simplify its fabrications, may be of benefit to engineers having similar projects to design, be it a hangar or the same principle applied to a factory or similar building of smaller truss spans, but of the same structural nature.

This structure started out to be the usual riveted structure of its type, until it was discovered as a result of preliminary design, that there was not enough money available to pay for the riveted steel required for the size structure set out in the appropriation made for its construction.

It was evident from these studies that a drastic design change had to be made, so after further study, it was finally decided to adopt the use of a welded structure even though it was known that it must be finally approved by a government authority supposed to be well known for its not too friendly feeling towards welded structures.

On this particular question it may be said that the approval by this authority proved to be only "supposed to be" for they co-operated to the
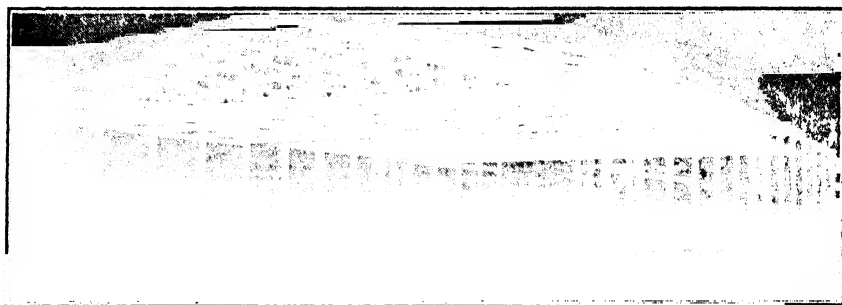
Fig. 1. Hangar partially erected.

fullest extent, thereby proving that one cannot always believe these so called "reputations."

Since the erection of this structure, engineers have asked why we did not adopt the usual welded girder-type of rigid frame, commonly used in structures of this type on long-span work.

There were certain considerations in this design which influenced the type of truss adopted and these were as follows:

1, A flat ceiling of insulating and sound proofing material was required over the entire hangar space.

2, Traveling supported craneway tracks were required over large areas of the building for removal of motors and other equipment from planes.

3, The type of horizontal sliding doors used at each end of the hangar as a matter of economy, required overhead track guides and bracing which worked out more economically by using the truss design.

4, The roofing material used was a well known type of asbestos protected metal and the ceiling construction of a wood fibre insulation board, produced a combination which for dead weight was very low with the further advantages of a large air space between the roof itself and the insulating ceiling. The soundproof qualities of this type of ceiling were considered, and due to the fact that work might be in progress on planes, noise from which work is very much absorbed, making the building a better place in which to work.

5, In the neighborhood in which this structure was to be built there was only one fabricator not equipped to bid on, fabricate and construct the truss type of structure, with the result of better competition for the job.

Design loads were those required by the building code of the city in which the structure was built, as were also the steel allowable unit stresses and weld values were used conforming to the A.W.S. Welding Code for Fusion Welding in Buildings using heavy-coated electrodes.

The original riveted design was made in accordance with recommendations of the A.I.S.C. and the usual shop and field practices for this type of structure.

The welded design followed the same general rules, except that advantage was taken of continuity in roof purlin construction and placement of members of trusses to secure full advantage of the material as I will show later.

A comparison of the two designs showed that the welded design made savings of weights of materials in the following specific places:

1, roof purlins because of method used to develop continuity.

2, trusses and wind bracing system because of no loss of material for holes deducted for tension members and the use of boxed angle sections for long compression members, and elimination of all large gusset plates.

3, columns, no holes to be drilled and less material required for connection of trusses and for anchor bolt connections at base of columns.

In the closest possible riveted design, there were 282 tons of steel, whereas in the welded design there were 221 tons, making a saving of 61 tons of steel.

It should also be noted that there were shop process saving secured through the fact that details of connections were so designed that there were no punched holes in any main member. This was due to connection holes having been punched in the connection angles, which in turn were welded to the main members. No holes were punched in any truss members, in purlins or in the main columns, which were heavy enough to require drilling for good rivet work.

This meant no templates and entire job was shop fabricated without any main member going through a punch shop and all steel was entirely welded in the assembly bay of the shop in which it was turned out.

Anchor bolt stiffener plates were welded to base of columns, after which the columns were milled for bearing on base plates and for bearing of top chord of truss at top of columns.

At this point, it might be well to state that the method of connection for field assembly of the members of this building, was designed for use of the erection seat and clip. These articles are shop welded to the steel where required to connect to each other in the field erection work, and so hold the members together prior to the time when the field welding can be done.

These articles were used throughout the job for connection of all steel members to each other and have certain definite advantages over field bolting, both in the shop work and in the field erection work in that they eliminate all punched holes.

The general shop process consisted of sending the material previously cut to length, into assembly lines.

Due to the diagonal bracing system there was a large number of irregular-shaped plates, which required no holes and which were cut from paper templates. These plates were moved into welding shop where, by the aid of small jigs, the erection seats were welded to these plates. This part of the work was handled on a production basis, certain welders being continually on this work.

The vertical and diagonal truss members were welded together in pairs, by certain other groups of welders. These completed members were placed in positions near the final assembly jig used for putting the trusses together.

The top and bottom chord members were handled on a line where the small gusset plates, required at certain panel points, were welded directly to the
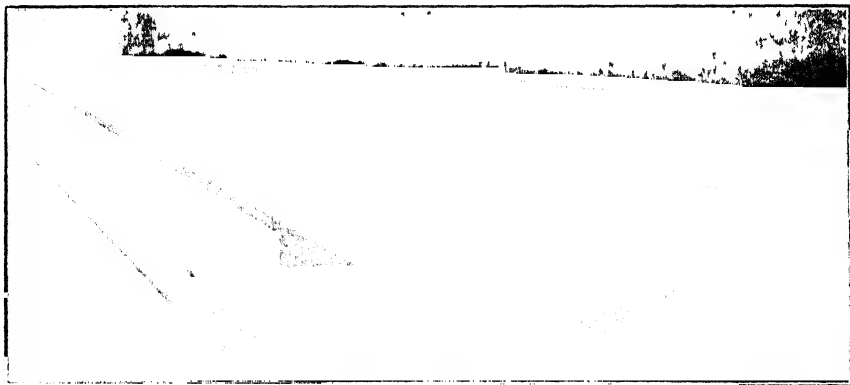
Fig. 2. Truss pile.

chord member, the small gussets having previously been prepared by grinding, for a V joint weld to the edge of the leg of the chord members, which it will be noted were tees made from split beams. After these welds were completed the welds were ground down, so that no interference would occur with the truss members which came down over this joint in the final assembly. On completion of this work, the plates previously prepared for the diagonal member connections were welded to these top and bottom chord members, at the positions in which they were required in the completed truss, the erection seats and clips being placed along with these plates so that on completion each top and bottom chord was completely assembled and ready for placing in the final assembly jig.

This jig, made up with members as long as half the length of the trusses, of two main members, spaced apart the distance between the top and bottom chords, was so arranged that when the chord members were placed on them, the chord members could be clamped securely in place, either in a straight position as for the top chord section or in a slightly curved position to make up the camber required in the chord sections.
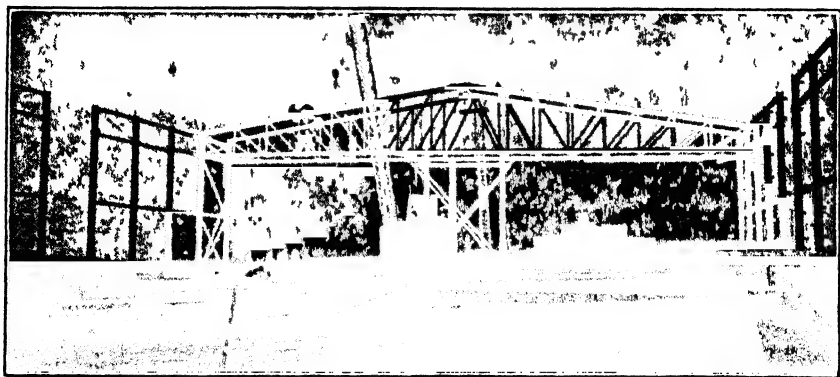
Fig. 3. Erection of trusses.

After these chords had been securely fastened to the jig then the web members of the truss were placed in position by selecting a previously fabricated pair of angles, driving a small wedge between them to open the ends, and sliding the open ends of the angle pairs to the proper position on the chords, at which location they were clamped in position, and tack welded after which the final welders followed up

This method of assembly allowed separate groups of men to work on the trusses at the same time, so that the assembly process and the final welding were completed in a remarkably short time for such large trusses

From this description, it will be understood that the previously described assembly left a completed truss, but with the members welded in place on only one side of the chords.

When upper side was complete, then the clamps were released, the truss lifted from the jig, moved to one side about ten feet away and turned over on skids in position for welding the opposite side, which was done by welders working in groups.

With this welding completed the shop assembly of the trusses was finished and they were moved to painting skids.

For the benefit of any one designing any similar trusses I would like to point

out, that the use of the split beam sections is best for top and bottom chords, for the outstanding leg of the T under normal conditions gives sufficient leg on which to place weld for connection of web members.

In the case of these particular trusses we found however that at some points it was necessary to get an additional depth of web in order to get sufficient weld length on the truss members. To accomplish this we used small narrow plates which were V welded to the upstanding leg of the T to give us more area for welding of the members.

This proved, with the grinding which was necessary, to be an expensive and slowing up operation, for the chords, which were heavy, had to be crane lifted and turned over for this operation on each side of these small gussets. Checking this over with the shop foreman, we found that it would have been cheaper to have used a split beam of deeper web, for the chords, even though we wasted a small amount of steel in the design of the truss, for these items of cost were reflected in the bid price on the job. In other words even though we were to use slightly more tonnage our completed truss would have cost less to build and this would have been reflected in the ton price on the job.

The use of boxed angle sections produces considerable saving in material required for compression web members. In welded trusses in which we have roof purlins framing so that tops of purlins are flush with top of chord of truss, we have found that pairs of channels placed toe to toe for vertical truss members, give a very simple connection condition for purlin connections to trusses, by making the connection to the back of the channel which in turn has been welded directly to the web of the T, thereby eliminating the necessity for gusset plates or the difficulty of making a welded connection on the outstanding leg of the usual pair of angles, which cannot be done without using punched holes in both angles and purlin.

On other trusses to secure the same condition we have used I beam section for the vertical truss members. This can be easily done by slotting the web of the I at each end, so that the stem of the T section chords passes through the web slot. The weld is then applied along the slot sides and the stem of the T. As there is a tendency for these I's to bend about the web connection, if any rough job handling of trusses takes place, this use of I's is only recommended when the webs of the I's can be tacked at the edge of the T flange to keep them from rotating on their vertical axes. These I's make a very good member for light trusses for they greatly simplify beam connections, to the vertical members of a truss.

Our experience indicates that the source of economy in most welded work exists in the ability to get away from all punched or drilled hole work in main members, and to design so that holes are only required in connection fittings themselves, then welding the fittings to the members to be attached.

The field erection work on this job proceeded in much the same manner as would have existed on a similar riveted job.

The columns were erected on base plates and bolts which had previously been grouted and placed. It had originally been intended to weld the two halfs of each truss together on the ground, but due to lack of capacity of the crawler crane derrick sent to job, it was necessary to erect each half truss using a small A frame with vertical adjustments at near the end position of each half truss. After each half was erected the A frames were adjusted to give proper camber to truss, after which the two parts were welded together.

As soon as a pair of trusses was erected then the ceiling, roof beams and bracing were placed. This process was repeated so that after the second pair had been erected with its filling in beams, then the short pieces of beams were

placed between the projecting, cantilever ends of the roof beams, which extended beyond the lines of each of the pairs or groups of trusses.

When a group of four trusses with their filling in beams had been erected and plumbed, then the field welding on this section was started and completed, while other trusses were being erected.

The welding of all bottom chord connections of trusses was postponed until all steel was completely erected, so that ample opportunity was given for truss deflections to take place, so that these deflections would not bend the columns as so often happens in these long span jobs. The results in this case were most satisfactory for all columns after welding of the bottom chord connection remained plumb.

It might be well to mention here that our general experience with welded trusses indicates, that they are less subject to deflection than similar riveted trusses, probably due to the fact that there is less possibility for movement in the connected parts of the truss members.
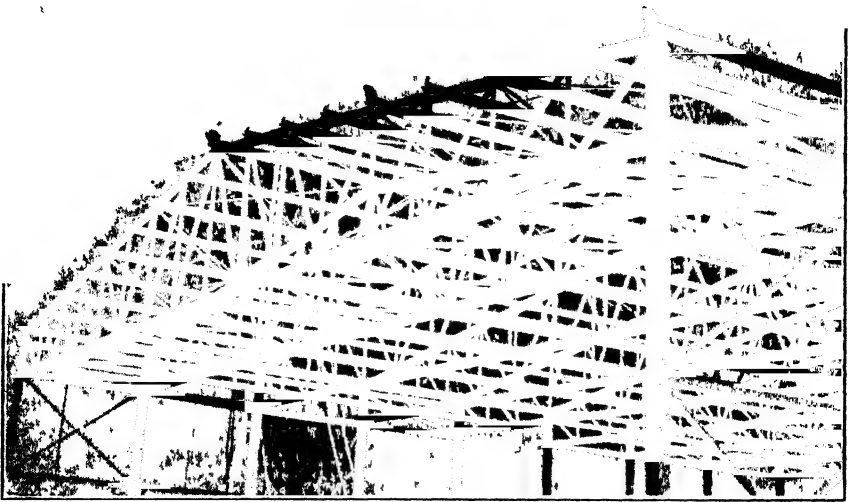
Fig. 4. End truss.

The contracts for this work were awarded as a fabricated job shipped F.O.B. job site and an erection contract covering erection of steel as delivered to the site

Because of the fact that this fabrication came under provisions of a Federal law requiring conformity to certain conditions, the contract could not be awarded to the low bidder, so it was awarded to a high bidder at $18,343 for the fabrication.

The contract for the erection, including field welding being subject to the same conditions recited above, was let to a qualifiying contractor at $8000. This figure was considered quite high and in light of the fact that the actual job payrolls, which included all men working on the job, was $3400 it would seem that this contractor came out fairly well on this job of welded erection.

The equipment required to erect the job was one crawler crane, and two gas driven welding machines.

It should also be stated that the shop fabrication figure developed to a price

Fig. 5. Bottom chord front bracing.

per ton for the welded steel fabrication which was the average ton price for riveted fabrication at the time this contract was let, so at least no penalty developed in the ton price for the welded job.

It was considered that the erection price per ton was probably $5 higher than the amount for which a similar riveted job could have been let.

This higher cost of the welded erection was undoubtedly due to lack of knowledge of what the actual field costs of such welded erection were. This seems to have been demonstrated by the payroll record kept on the job and leads me to the conclusion that the contractor's erecting superintendent was correct, when after completing the work he was of the impression, that were he to do another job of similar nature, by use of a heavier derrick to enable him to raise a complete truss, he could cut his field costs so considerably, that while he could erect this type of work as fast, as riveted work, the field welding would have been more economical than riveting.

It was considered in view of the known tonnages derived from the original riveted design and the final welded design, that the net saving due to the use of the welded design amounted to approximately $6,163 which brought the cost of the erected steel frame within the original appropriation.

In conclusion, the authorities in charge of this building were so well impressed with the welded structure, that two additions to the original building have been entirely of welded construction, although they are of entirely different type, being of shorter span construction. This building has been recommended by those national authorities having it in charge as a design to be copied by other groups throughout the states, as the most economical type of hangar to use and had it not been for the stoppage in use of steel, more of these would have been constructed, instead of the numerous temporary wood hangars now being constructed at costs greater than this steel hangar.

All work was done by qualified welders working under supervision of a qualified inspecting company. The erection seats and clips used in this work are patented articles which can be purchased in the open market.

The writer regrets that he cannot give names of the authorities back of this project or of the contractors who so willingly co-operated in undertaking the fabrication and construction of a welded project, which was, as they said the largest piece of building welded work their shop had ever done.

Chapter II—Efficiently Rigid Arc Welded Connections

By R. P. V. Marquardsen,
Structural Designer, The Sanitary District of Chicago, Chicago, Illinois.

R. P. V. Marquardsen

Subject Matter: A detailed design for a welded connection between beam and column that will have a shear value and resisting moment equal to those of the beam.

Although the process of arc welding, as applied in structural engineering, has progressed rapidly in recent years, it seems to the writer that the one great opportunity for profiting from this process has been overlooked entirely, viz., the development of efficiently rigid connections for use between the several members of a structure.

By an "efficiently rigid connection" the writer means a connection having a shear value and resisting moment equal to, or greater than, the shear value and resisting moment of the supported beam or girder.

The chief advantages derived from the development and use of efficiently rigid connections may be summarized as follows:

1, a reduction in the quantity of steel required for girders and beams, of not less than 25 per cent

2, an increase in the allowable span length (as limited by deflection requirements) of not less than 35 per cent, for any given beam supporting a given total load

3, a more nearly rational basis for designing columns, due to the fact that the moments can be determined more accurately

In order to develop mathematically an efficiently rigid connection, an analysis of the strength of the various types of welds in general use is a prerequisite.

Such an analysis need not necessarily be absolutely correct mathematically, as long as the results obtained are known to be on the side of safety and are fairly accurate. As a matter of fact, the writer is of the opinion that the simpler an analysis is, the greater in all probability will be the number of engineers who will take the time to acquaint themselves with it.

In order to simplify the analysis that follows, welds will be divided into four general classes:

1, tension welds, which will include all welds that are subject to direct tensile stresses only

2, compression welds, which will include all welds that are subject to direct compressive stresses only

3, bending welds, which will include all welds that are subject to bending stresses.

4, shear welds, which will include all welds that are subject to shearing stresses principally

Each of these classes will be subdivided further into several types, depending on the shape of the cross-section of the weld, as for instance rectangular welds, triangular welds, sector welds, V welds, double-V welds, U welds, double-U welds, etc.
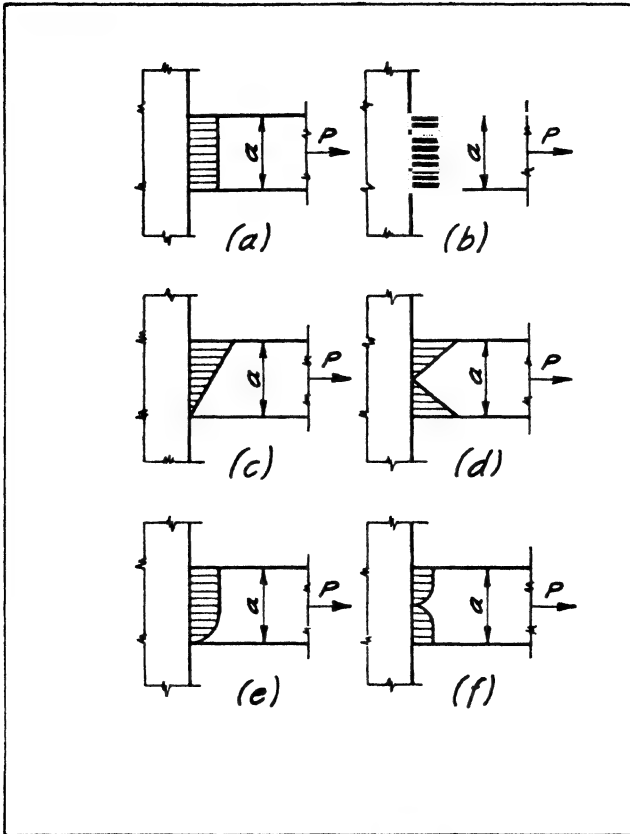
Fig. 1. Tension welds.

The following nomenclature will be used:

f_T = allowable unit tensile stress in the weld material, in pounds per square inch.

f_C = allowable unit compressive stress in the weld material, in pounds per square inch.

f_B = allowable unit bending stress in the weld material, in pounds per square inch.

f_s = allowable unit shearing stress in the weld material, in pounds per square inch.

a = width of weld, in inches, subject to direct tension or compression, in tension and compression welds.

b = depth of "cantilever" in bending welds, in inches.

c = length of "cantilever" in bending welds, in inches.
d = dimension, in inches, of either side of the weld, in triangular shear welds.
e = radius of the weld, in inches, in sector shear welds.
l = length of the weld under consideration, in inches.
S_T = total working strength of tension weld, in pounds.
S_C = total working strength of compression weld, in pounds.
S_B = total working strength of bending weld, in pounds.
S_S = total working strength of shear weld, in pounds.

Tension Welds—In Fig. 1 are shown several types of tension welds. Evidently the strength of these welds is the same, inasmuch as the shape of the cross-section of any tension weld, that is, whether rectangular, single or double V or U, obviously is immaterial as far as strength is concerned.

The working strength of tension welds therefore may be expressed by the following formula:

$$S_T = a\,l\,f_T \qquad (1)$$

Compression Welds—Compression welds are similar to tension welds, the only difference being that the welds are in compression instead of in tension. The working strength of a compression weld therefore is given by the following formula:

$$S_C = a\,l\,f_C \qquad (2)$$

Bending Welds—In Fig. 2 is shown a bending weld. In analyzing the strength of this weld it is assumed that a tensile force P is applied as indicated and that bar A is so held that only tensile stresses will occur at right angles to section C-C of the weld. Evidently a similar analysis may be employed if a compressive force is applied in the same manner.

The weld may be considered to be a cantilever, rigidly attached to bar A and supporting a varyingly distributed load whose intensities are proportional to the ordinates of the elastic curve of the cantilever, with the pointed end of the cantilever as the origin, the maximum load intensity being equal to f_T. A parabola with its origin at the point of support very nearly fulfils this condition, (See also Fig. 3).

Considering a unit length of weld, the total load on the cantilever is $\frac{2}{3} c\, f_T$, and f_T being the allowable unit tensile stress, the total strength of the weld (per unit of length), as far as section C-C is concerned, is $\frac{2}{3} c\, f_T$. For all practical purposes only direct tension occurs at this section.

The total shear along the line of support of the cantilever (section B-B) is equal to the total load $\frac{2}{3} c\, f_T$. The section of the cantilever is rectangular at the support, and the maximum unit shear at the section, being one and one-half times the average, is therefore $\frac{2}{3} c\, f_T$ divided by $\frac{2}{3} b = \frac{c}{b} f_T$. This means that, in order for the weld to be as strong in shear at section B-B as it is in tension at section C-C, the value of $\frac{c}{b}$ must be equal to $\frac{f_S}{f_T}$. If c is equal to b and if $\frac{f_S}{f_T}$ is equal to only $\frac{11{,}300}{13{,}000}$, the total strength of the weld (per unit of length), as far as shear along section B-B is concerned, is $0.580\, c\, f_T$.
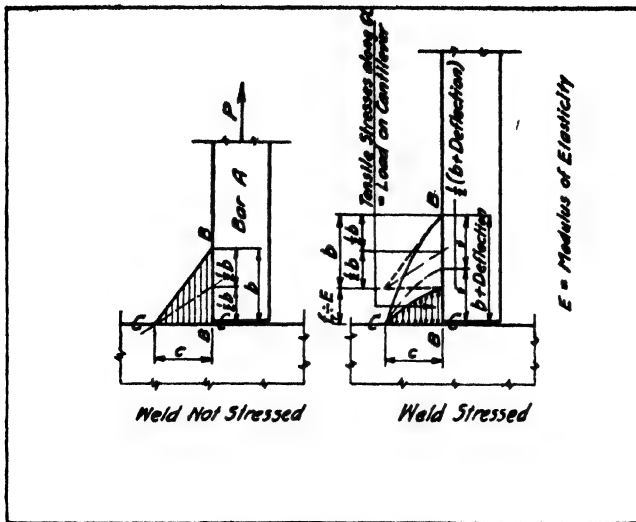
Fig. 2. Bending weld.

The maximum bending moment at the support is $\frac{2}{3}$ c f_T times $\frac{3}{8}$c $= \frac{1}{4} c^2 f_T$. The section modulus of the section being $\frac{1}{6}$ b^2, the maximum fiber stress is therefore $\frac{1}{4} c^2 f_T$ divided by $\frac{1}{6} b^2 = \frac{3}{2} \frac{c^2}{b^2} f_T$. If b is equal to c, the maximum fiber stress is $\frac{3}{2} f_T$, and the strength of the weld would be only $\frac{2}{3}$ c f_T divided by $\frac{3}{2} = \frac{4}{9}$ c f_T, but if b is made $\sqrt{\frac{3}{2}}$ greater than c (= 1.22 c), the strength of the weld, as far as bending stresses are concerned, will be as strong as the weld is along section C-C, assuming that f_B is equal to f_T. Obviously b should be made equal to 1.22 c for economic reasons.

The working strength of bending welds therefore may be found by applying the following formulas:

When b is equal to c:

$$S_B = \frac{4}{9} c\, l\, f_T \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

When b is equal to 1.22 c:

$$S_B = \frac{2}{3} c\, l\, f_T \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Shear Welds—In Fig. 4 are shown two bars, A and B, welded together on two sides with shear welds. View (a) is a plan, (b) an elevation, and (c) and (d) alternate cross-sections of the bars and shear welds. The cross-section at (c) shows triangular shear welds and the cross-section at (d) shows sector shear welds. The two bars A and B, for the sake of simplicity in analyzing the strength of the welds, are assumed to have equal cross-sectional areas.

The ordinates of the curves shown at (e) indicate the distances that the

cross-sections of the bars (along the length of the weld) move from their original positions under the varying tensile stresses in the bars. The ordinates of the curve above line a-b represent the movements towards the right of the cross-sections of bar A, and the ordinates of the curve below line a-b represent the movements towards the left of the cross-sections of bar B. Either curve may be considered to be a parabola (which assumption is on the side of safety), the origin of the bar A curve being at a and the origin of the bar B curve being at b.

Inasmuch as all corresponding cross-sections of the two bars move in opposite directions, the sum of any two corresponding ordinates represents the total movement (away from each other) of the two cross-sections under consideration; and inasmuch as the unit shearing stress in the weld at any point is proportional to the total movement of corresponding cross-sections at that point, it follows that the sum of the ordinates also represents the unit shearing stress in the weld.

The total area of the ordinates diagram is $\frac{2}{3} l f_s$, which multiplied by the minimum depth of the weld gives the total strength of the weld per side.

For welds of triangular cross-section, as shown at (c), the minimum depth of the weld is $\sqrt{\frac{1}{2}}\, d$, and the total working strength of the weld per side is therefore $\sqrt{\frac{1}{2}}\, d$ times $\frac{2}{3} l f_s$, or

$$S_s = 0.472\, d\, l\, f_s \qquad (5)$$

For welds whose cross-sectional area is the fourth part of a circle, as shown at (d), the depth of the weld is equal to e, and the total working strength of the weld per side may therefore be found by applying the following formula:

$$S_s = \frac{2}{3} e\, l\, f_s \qquad (6)$$

In other words, the total working strength of a triangular shear weld is only about 70% of the total working strength of a sector shear weld, assuming that d is equal to e.

Efficiently Rigid Connections—Formulas for ascertaining the working strength of tension, compression, bending, and shear welds having been derived, the design of a typical efficiently-rigid connection can now be developed.

As an example, an efficiently rigid connection will be developed between a 36-inch wide-flange structural-steel beam and the flange of a 14-inch column. The result of this study is shown in Fig. 5 and references to this figure will be made throughout the design of the connection.

For convenient reference, the properties of the 36-inch beam are listed below:

Total depth of beam = 35⅞ inches
Width of flange = 12 inches
Thickness of flange = 15/16-inch
Area of flange = 11.25 square inches
Depth of web = 34 inches
Thickness of web = ⅝-inch
Area of web = 21.25 square inches
Section modulus of beam = 502.9 inches^3

The following numerical values for allowable unit stresses in the weld material will be used:

f_T = 13,000 pounds per square inch
f_C = 15,000 pounds per square inch
f_B = 13,000 pounds per square inch
f_s = 11,300 pounds per square inch

The allowable unit stress in the beam and the connection plates will be taken equal to 20,000 pounds per square inch for tension, compression, and bending and equal to 15,000 pounds per square inch for shear.

The design of an efficiently rigid connection may conveniently be made in three separate operations, viz., designing the

1, top-flange connection
2, bottom-flange connection
3, web connection

and each of these three designs may be subdivided further into designs for (a) welds between connection plates and girder, and (b) welds between connection plates and column.

This procedure will be followed in the design of the typical connection under consideration.
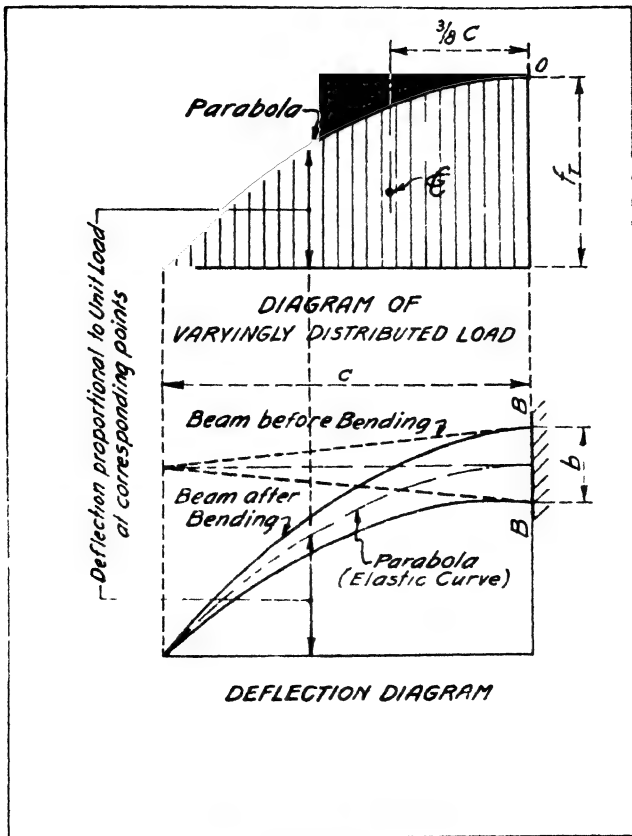
Fig. 3. Deflection diagram.

Top-Flange Connection—The cross-sectional area of the top flange is 11.25 square inches and its total working strength is therefore 225,000 pounds.

A 9-inch wide by 1¼-inch thick connection plate has the same cross-sectional area and is therefore adequate.

To allow for necessary adjustments during erection, only field welds should be used, and overhead welds should therefore be avoided.

The welds between the connection plate and the beam may consist of:

1, bending weld ($1\frac{1}{4} \times 1\frac{5}{8} \times 9''$):
 By Formula (4) $= \frac{2}{3} \times 1\frac{1}{4} \times 9 \times 13{,}000 \quad = 97{,}500$ pounds
2, sector shear welds (each $1\frac{1}{4} \times 7''$):
 By Formula (6) $= 2 \times \frac{2}{3} \times 1\frac{1}{4} \times 7 \times 11{,}300 \quad = 131{,}800$ pounds

Total = 229,300 pounds

Or, if it is desired to use right-angle equilateral triangular welds, the following combination may be used:

1, bending weld ($1\frac{1}{4} \times 1\frac{1}{4} \times 9''$):
 By Formula (3) $= \frac{4}{9} \times 1\frac{1}{4} \times 9 \times 13{,}000 \quad = 65{,}000$ pounds
2, triangular shear welds (each $1\frac{1}{4} \times 1\frac{1}{4} \times 12''$):
 By Formula (5) $= 2 \times 0.472 \times 1\frac{1}{4} \times 12 \times 11{,}300$
 $= 160{,}000$ pounds

Total = 225,000 pounds

Other combinations, of course, could be used.

The welds between the connection plate and the column may consist of:

1, tension weld ($1\frac{1}{4} \times 9''$):
 By Formula (1) $= 1\frac{1}{4} \times 9 \times 13{,}000 \quad = 146{,}000$ pounds
1, bending weld ($1\frac{1}{16} \times 1\frac{5}{16} \times 9''$):
 By Formula (4) $= \frac{2}{3} \times 1\frac{1}{16} \times 9 \times 13{,}000 \quad = 83{,}000$ pounds

Total = 229,000 pounds

The total potential stress in the top flange of the beam is now transferred to the adjacent flange of the 14-inch column.

To transfer one-half of the stress to the other flange of the column to obtain equal distribution, two plates (one on each side of the column web) may be shop-welded to the flanges.

The cross-sectional area of these plates need only be one-half of the area of the connection plate. Their center lines should coincide with the center line of the connection plate, as indicated in Fig. 5. If each plate is 5-inch x $\frac{5}{8}$-inch, the welds to each column flange per plate may consist of:

1, tension weld ($\frac{5}{8} \times 5''$):
 By Formula (1) $= \frac{5}{8} \times 5 \times 13{,}000 \quad = 40{,}600$ pounds
1, bending weld ($\frac{5}{8} \times 5''$):
 By Formula (3) $= \frac{4}{9} \times \frac{5}{8} \times 5 \times 13{,}000 \quad = 18{,}100$ pounds

Total = 58,700 pounds

The welds of course can be made in the shop.

Bottom-Flange Connection—The connection plate for the bottom flange should be shop-welded to the column and be provided with a vertical stiffener (as indicated in Fig. 5) so that it may be used as a seat for the beam during erection. Also, it must be wider than the beam flange in order to furnish a base for field welding to the beam.

A 14-inch x $\frac{7}{8}$-inch plate will fulfil this requirement and will be adequate as far as cross-sectional area is concerned.

The welds between the connection plate and the beam may consist of:

2, sector shear welds (each $\frac{7}{8}'' \times 17''$)
 By Formula (6) $= 2 \times \frac{2}{3} \times \frac{15}{16} \times 17 \times 11{,}300 \quad = 225{,}000$ pounds

The welds between the connection plate and the column may consist of:

1, tension* weld (7/8 × 14")
  By Formula (1) = 7/8 × 1 × 14 × 13,000* = 159,000 pounds
2, bending welds (each 5/16 × 3/8 × 14")
  By Formula (4) = 2 × 2/3 × 5/16 × 14 × 13,000 = 76,000 pounds

Total = 235,000 pounds

*(Assuming that there might be a reversal of stress due to wind forces, it would seem advisable to use allowable tensile stresses rather than allowable compressive stresses).
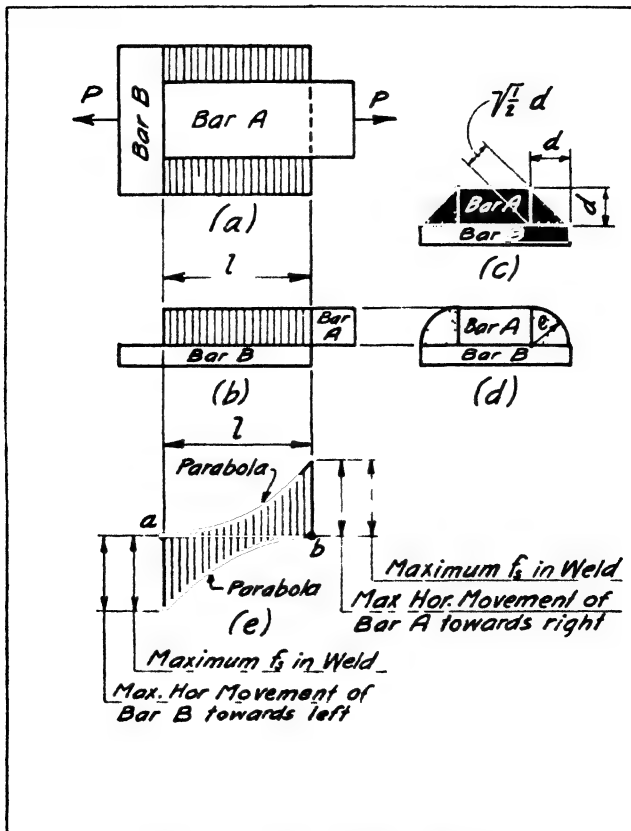
Fig. 4. Two bars welded together.

The welds of the stiffener plate need only be nominal: A 3/8-inch continuous weld on each side will suffice, (See Fig. 5).

The same size transfer plates and welds used at the elevation of the top flange of the beam, to transfer one-half of the stress from one column flange to the other, may be used at the elevation of the bottom flange of the beam.

Web Connection—The cross-sectional area of the web is 21.25 square inches and its total allowable working strength is therefore 425,000 pounds.

Two 32-inch x $\frac{3}{8}$-inch connection plates could be used as far as area is concerned, but difficulty would be encountered in getting sufficiently strong welds. Two 32-inch x $\frac{3}{4}$-inch connection plates will fit the conditions better.

The welds between each of these connection plates and the beam may consist of:

1, bending weld ($\frac{3}{4} \times 1\frac{5}{16} \times 32''$):

By Formula (4) $= \frac{2}{3} \times \frac{3}{4} \times 32 \times 13{,}000 \qquad = 208{,}000$ pounds

which multiplied by 2 gives the total working strength of the two plates, or 416,000 pounds. This is 9,000 pounds less than the working strength of the web, but this deficiency, if so desired, may be made up by the use of a few plug welds as indicated in Fig. 5.

The welds between each connection plate and the column may consist of:

1, tension weld ($\frac{3}{4} \times 32''$):

By Formula (1) $= \frac{3}{4} \times 32 \times 13{,}000 \qquad = 312{,}000$ pounds

which multiplied by 2 is equal to 624,000 pounds for the two plates.

Neither the total working strength of the web nor that of the weld material is, of course, ever fully developed in bending, since the unit stress varies from zero at the center of the web to a maximum at the top and bottom, but it would seem logical to make the weld at least as strong as the web itself in order to obtain the same stiffness throughout.

General Check—The designs of the top-flange, bottom-flange, and web connections constitute the entire design of the efficiently rigid connection, but a general check on the connection as a whole may be made as follows:

The section modulus of the beam is 502.9 inches^3 and the total resisting moment is therefore 10,058,000-inch pounds.

The total resisting moment of the top-flange, bottom-flange, and web connections may be computed roughly in the following manner:

The distance between the centers of the top and bottom connection plates is $36\frac{15}{16}$ inches and the allowable working strength of either connection is at least 225,000 pounds; hence, the resisting moment of these two connections is $225{,}000 \times 36\frac{15}{16} = 8{,}310{,}000$-inch pounds.

The minimum weld strength of the web connection is 416,000 pounds. The depth of the plates is 32 inches, and the distance between the centers of the top and bottom connection plates is, as stated above, $36\frac{15}{16}$ inches. The total resisting moment of the web connection (by the section-modulus method) is therefore

$$\frac{416{,}000 \times 32}{6} \times \frac{32}{36\frac{15}{16}} = 1{,}920{,}000\text{-inch pounds}$$

which, added to the resisting moment of the top and bottom flange connections, makes a total of 10,230,000-inch pounds for the efficiently rigid connection and is slightly greater than the resisting moment of the beam.

The allowable total shear on the unstiffened web of the 36-inch under consideration is 268,800 pounds.

The minimum shear value of the connection welds is the shear strength of the welds between the connection plates and the beam, which by Formula (5) is equal to

$$2 \times 0.472 \times \frac{3}{4} \times 32 \times 11{,}300 = 256{,}000 \text{ pounds.}$$

This is slightly less than the allowable shear on the web, but it should be good enough for all practical purposes inasmuch as shear seldom governs the size of the beam. If so desired, a few plug welds could be added to compensate for the deficiency, or the welds could be changed to sector welds.

Concluding Remarks—The writer does not claim that the foregoing analysis of the strength of the various types of welds is absolutely correct mathematically, nor that the preceding development of efficiently rigid connections is the only correct solution. His chief purpose has been to call attention to a great opportunity for advancing the arc welding industry that seemingly has been overlooked and incidentally to point out the steps that could be taken to remedy the situation.
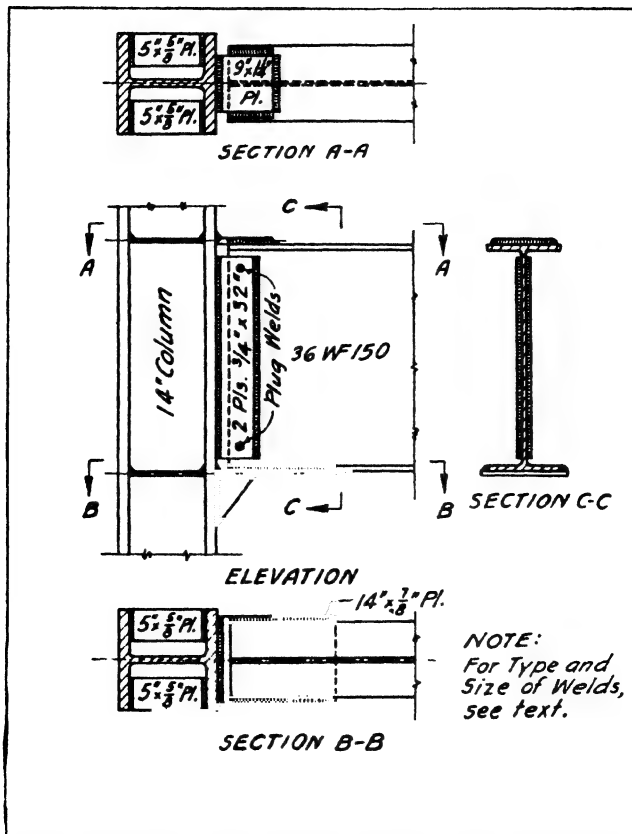
Fig. 5. Efficiently rigid connection between beam and column.

The present practice among structural engineers (and, by the way, the only one sanctioned by many city codes) is to design the various beams and girders in a building as simple beams.

Nor is this practice very much out of line where so-called standard riveted connections are used, as a thorough analysis of such connections will show quite readily. As a matter of fact, the angles of all standard riveted connections are stressed beyond the elastic limit and to such an extent that the resisting-moment value of the connections as a whole is very small—practically nil.

But handbooks for riveted connections are at hand and it is so easy to follow the line of least resistance; hence, riveted connections and simple-beam designs! ! !

And, now, what steps could be taken to remedy the situation?

The writer suggests that the James F. Lincoln Arc Welding Foundation prepare (or arrange to have prepared) for general distribution among structural engineers, designers, and draftsmen, and at a nominal price, a real "Handbook on Welding for Structural Engineers", similar in character to the handbook issued by the steel companies or by the American Institute of Steel Construction.

Such a handbook should contain, in addition to the usual tables and general data of interest to structural engineers that are found in the other handbooks referred to above, a thorough analysis of the strength of the various types of welds and (instead of tables for standard riveted connections and other rivet information) tables for standard efficiently rigid arc welded connections, properly arranged for ready reference. It should also contain a treatise showing how such standard arc welded connections should be designed. In short, the handbook should be a reference book and a textbook combined, free from all advertising matter.

Any opposition by city codes to a rigid-frame design surely can be overcome if adequate proof is presented that really rigid connections can be constructed.

Proportionate Cost Saving—The proportionate cost saving per complete unit, that is, by using an efficiently rigid arc welded connection instead of a riveted connection, is not found in the actual costs of the two types of connections, which probably do not differ a great deal, but in the quantity of steel saved in the beam or girder occasioning the connection.

For instance, if the size of a given beam with a riveted connection is found by using a bending moment equal to $\frac{w\,l^2}{8}$, the size of the same beam with an efficiently rigid arc welded connection would only be required to take care of a bending moment equal to $\frac{w\,l^2}{12}$ or less, or in other words there would be a proportionate saving of at least 25 per cent.

Estimated Total Annual Gross Savings—The total annual gross savings accruing from a general adoption in the United States of efficiently rigid arc welded connections for use in structural steel buildings may be estimated as follows:

Assume that the annual United States production of structural shapes and plates is 2,500,000 tons for a normal pre-war year, and that about 50 per cent of this tonnage is used in buildings. Assume further that about 65 per cent of the building steel represents girders and beams, the remaining 35 per cent being columns.

The total steel used for girders and beams would therefore be 2,500,000 $\times$ 0.50 $\times$ 0.65 = 810,000 tons. The total saving of this tonnage is not less than 25 per cent or about 200,000 tons, which at an erected price of $100 per ton gives a total annual gross saving of $20,000,000.

Increased Service Life, Efficiency, and Social Advantages—There would probably be no increase in service life accruing from the adoption of efficiently rigid arc welded connections, but neither would there be any decrease.

Any efficiency accruing would be in the saving of time and labor in connection with the preparation of the detailed plans for the building. Such saving of time and labor, as any structural engineer can readily perceive, would not be inconsiderable, provided a real "Handbook on Welding for Structural Engineers", such as is described above, is at hand.

Among the social advantages accruing from the use of efficiently rigid arc welded connections may be mentioned: (a), the elimination of a lot of noise during erection; (b), lower total cost of the building; and, (c), a more rigid structure with less vibration and less swaying during severe wind storms.

Data on Costs and Cost Comparisons—As previously stated, the proportionate cost saving in using efficiently rigid arc welded connections instead of the usual riveted connections is found in the quantity of steel saved in the girder or beam occasioning the connections. The cost of the connections themselves evidently is very small as compared with the cost of the girder or beam, and hence there would be no object in making elaborate comparisons between the cost of a riveted connection and the cost of an efficiently rigid arc welded connection, especially since the actual costs of the two types of connections probably would be about the same at any rate.

Final Comment—The foregoing discussion should show conclusively that the general adoption of efficiently rigid arc welded connections in the design and construction of structural steel frames for buildings would constitute real progress in the process of arc welding.

Chapter III—Steel and Concrete Bridges Compared

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Subject Matter: Girder-type highway bridges. Detailed cost data for two bridges built near each other and at the same time One bridge was of an all welded design, with full composite action of the concrete floor slab The other bridge was of conventional riveted design with a limited amount of welding on secondary members and making but little use of the slab in composite action.

Modern bridge design demands strict adherence on the part of the designer to the economical use of materials. This was especially true throughout 1940 and 1941, in order that increased demand for new highways and wider highways by the users of these facilities could be handled within the limits of the highway gasoline tax funds available for such purposes. As highway bridges are a necessary part of any highway building program, it was necessary to make the available bridge construction funds stretch over as many projects as possible.

Present war production demand for bridge building materials makes it even more necessary that structures be designed to meet the essential load-carrying requirements with the most effective use of materials.

Economical bridge design produces a least combined cost of bridge superstructure and substructure to satisfy given live load specifications; subject to underclearance requirements for navigation or, in the case of a grade separation structure, highway or railway traffic clearances The majority of bridges are, therefore, in the short-span range between 20 and 100 feet and, individually, attract little attention from engineers at large.

On occasion, it is necessary to construct a bridge of major proportions across an important waterway. Considerable attention is focused upon these structures because of their size; yet, in terms of financial expenditures per year, the small bridge of short-span length deserves real attention, because, in the two-year period covering 1940 and 1941, approximately 30 million dollars was spent in the United States by various state and municipal agencies on bridges with spans of 40 to 80 feet. As very few individual bridge projects exceed this expenditure but require considerably more than two years to construct, the small bridge of short span deserves considerably more attention and thought than it now receives.

A 24 per cent reduction in expenditure for bridges in the 40 to 80 foot span range is worth approximately $2,800,000 annually. This paper will show that an all-welded composite steel beam and concrete slab bridge in the 60 foot span range will save 24 per cent of the cost of the ordinary type of

steel beam and concrete slab bridge, which does not utilize the concrete slab to resist stress

It will also show that an all-riveted design can hardly justify the use of the slab in a composite girder section, as the high cost of providing a riveted shear key between slab and girder, absorbs all but 3 per cent of the saving.

It will show that the composite steel beam and concrete slab design is 16 per cent more economical than an all-reinforced concrete design in the 60-foot span range, whereas, the ordinary riveted type of steel beam and concrete slab design costs 10 per cent more than the reinforced concrete design in this span range Prior to the use of composite steel and concrete slab designs, it was more economical to use reinforced concrete up to spans of 60 to 80 feet; the variation in this length being determined by the relative prices for structural steel, reinforcing steel, and concrete in any one locality

Increased use of all welded composite steel beam and concrete slab bridges, will bring the economical span range from 60 to 80 feet down to 40 or 50 feet, as well as secure other advantages described hereinafter that are not directly reflected in construction cost
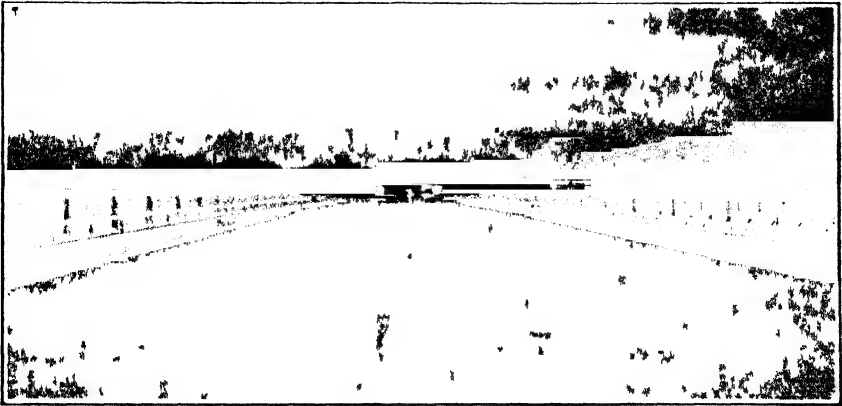
Fig. 1. Structure "A", view along center line.

While this paper is primarily designed to show advantages of welding in structural steel bridge construction, there are other less tangible but important considerations that favor the use of structural steel in bridge construction over reinforced concrete Plastic flow of reinforced concrete subjected to high compressive stress, becomes appreciable in long-span bridges of shallow depth, and results in poor riding qualities on the bridge deck due to excessive dead load deflections between piers over a period of time This undesirable characteristic is not taken into consideration in determining construction cost, but should merit considerable attention, as the center traffic stripe, sufficient roadway width, and the presence (or absence) of a smooth riding surface constitute the only items of immediate interest to the public highway user

Two all welded highway bridges, featuring use of the concrete roadway slab as an integral part of the steel girder section, have been designed by the writer and constructed by his organization during the two-year period, 1940 to 1942. These bridges, referred to hereinafter as Structure "A" and Structure "B", were designed and constructed to conform to American Welding Society specifications, which, however, were not at that time, and are not

Fig. 2. Structure "A", oblique side view.

now recognized by the American Association of State Highway officials for main stress carrying members.

The A.A.S.H.O. viewpoint on welding is stated in their 1941 Specifications as follows:

"Welding is not permissible in main members or their connections where the failure of the weld would endanger the stability of the structure."

Briefly, this viewpoint says: "Welding is not reliable." The writer firmly believes the reverse to be true, assuming intelligent designing for welding, and carefully planned shop and field welding procedures.

As the two bridges mentioned did not lie on Federal Aid Highway routes, it was possible to construct them without adherence to the welding restrictions set forth in the A.A.S.H.O. Specifications.

By coincidence, Structure "A" was adjacent to, but on a different highway route than another bridge to be referred to as Structure "C". Both bridges cross the same river, and are within two miles of each other, and were advertised for bids within a three-month's period. Structure "C" is on a Federal Aid Highway route, however, and could not employ welding for main members.

The concrete slab on Structure "C" was not allowed for composite action to resist dead load, as welded shear keys were used. The bureau did, however, permit its consideration for live load only in view of the relative improbability of maximum live loads ever being on the structure.

It is therefore possible to show comparative costs of the all welded design with full composite action of concrete slab versus a similar riveted design, with a limited amount of welding on secondary members, and relatively little use of the slab in composite action.

Typical details of Structure "A" are reproduced herein, together with detailed estimates of welding cost, and probable riveting cost if riveting had been used. Structure "A" did not conform in all respects to the plans, however, for construction of the girder field splices. The contractor elected to mill the 61-foot-span rolled girder beams to exact length, to obtain ⅛-inch field welding clearance, rather than use the filler bar arrangement shown on the plans. Difficulties arose due to joints not matching up to give a uniform ⅛-inch clearance. Further difficulties appeared in erecting, as fabricated lengths did not agree with pier locations. It was agreed on the job that the filler bar arrangement, called for on the plans, was preferable to the one used.

Structure "B" conformed to the plans, but was rather poorly fabricated. One noticeably bad shop error was scarfing the bottom flanges of the rolled girder beams from under side, instead of top side, requiring all overhead

welding on the bottom flange splices instead of downhand flat welding as had been planned.

Construction pictures of Structures "A" and "B", are reproduced here in Figs. 1 to 15 inclusive.

1. **Composite Girders**—Welding offers large economies in the design of composite steel beam and concrete slab bridges, in which the concrete slab is used as the top flange of a "tee" girder section.

Very few composite steel and concrete bridges have been built, because, among other reasons, the expense of an adequate riveted shear connection between slab and girder is prohibitive. The writer has developed satisfactory construction details for this type of bridge, using an all-welded design in steel with butt welded field splices in heavy rolled beams and welded shear keys. Two structures of this type have been built by the writer's organization and are the first of their particular kind to the best of his knowledge.

Rolled steel beam and riveted steel plate girder spans represent one of the earliest modern types of bridges. Scientific development of design and construction of reinforced concrete to its present high standard of quality has led to the use of a concrete deck slab supported upon longitudinal steel beams or girders. This highway bridge type is the most successful one ever developed, as "time" deflection of the concrete slab due to plastic flow produces transverse deformation only and does not affect the surface riding qualities of the bridge.

Very few bridges of this type, however, have used the concrete slab as a top flange. This has been due primarily to the expense of developing a good riveted shear key to resist the horizontal shearing stresses created between the top girder flange and the concrete slab that occur whenever the girder section receives load and is deformed by the resulting bending moment. To ignore this stress is to assume that the slab will slip along the top flange of the steel beam. Actual results show an undetermined amount of friction. Because it is undetermined, two bad effects result:

1. The ability of the slab to resist stress is neglected, resulting in the use of an excessive amount of steel in the girder.

2. Dead load deflections cannot be accurately determined. This frequently results in undesirable riding qualities of the finished bridge deck, when an estimated (rather an assumed) deflection fails to materialize, or is excessive. A positive shear connection permits an accurate determination of deflection of the composite section, subject only to the usual variation in modulus of elasticity of the concrete.

Fig. 3. Structure "B", view along center line.

Welding is ideal to overcome this condition as it permits practically any type of key to be connected to the flange using fillet welds of proper length and size to develop the horizontal shearing stresses.

2. **Shear Keys**—A riveted shear key on a rolled beam requires the drilling of holes in an otherwise blank top flange. (All of the deeper wide flange sections have a flange too thick to punch).

An angle shear key is probably the only satisfactory type using rivets, but it requires a horizontal leg of sufficient length to accommodate a line of rivets. The vertical angle leg, however, is the only useful part of the key as the vertical area in contact with the concrete times the permissible unit bearing stress against concrete in a confined area determines the value of the key. As this vertical leg is subjected to heavy bending stress a fairly thick leg is necessary to permit any reasonable height of angle. As the horizontal leg must be equally thick and of sufficient width to accommodate rivets, 50 per cent or more of the angle weight is wasted in engaging rivets rather than resisting bearing shear.
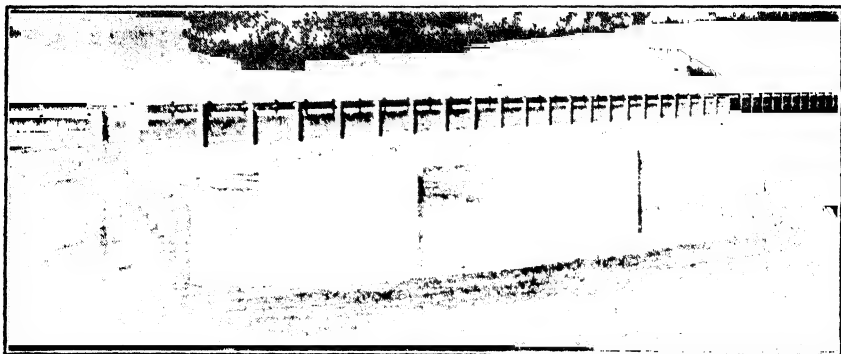
Fig. 4. Structure "B", oblique side view.

Zee shapes have been used for this purpose but are difficult to obtain due to infrequent rolling schedules and require even more metal. They do serve to lock the slab down to the beam, which, however, is an advantage more apparent than real, because bending stresses in a beam do not cause vertical separation of beam elements.

A welded shear key comparable to a riveted angle is a single bar of proportionate height and thickness welded to the flange. No metal is wasted; all of the key is used to resist bearing. A welded key therefore weighs 50 per cent or less than a riveted key of equal shear value.

From a practical standpoint further economies appear. Rivets in an angle must be arranged symmetrically in pairs using not less than two rivets to secure equal loading. This means that the shear key value changes by increments of 12000 pounds or 16000 pounds (for ¾-inch or ⅞-inch rivets). Welded shear keys may be proportioned to any shear key value, using a size and length of filet weld to meet exact requirements.

Considerable waste is therefore present in the riveted arrangement, as it is unusual when equal strengths will result in both rivets and angles; further, angle widths in the desired range vary by ½-inch units, whereas, flat bars for welding may be obtained from stock in ¼-inch increments. Extreme flexibility in design is therefore obtainable with the welded key in addition to the initial weight saving of 50 per cent or more.
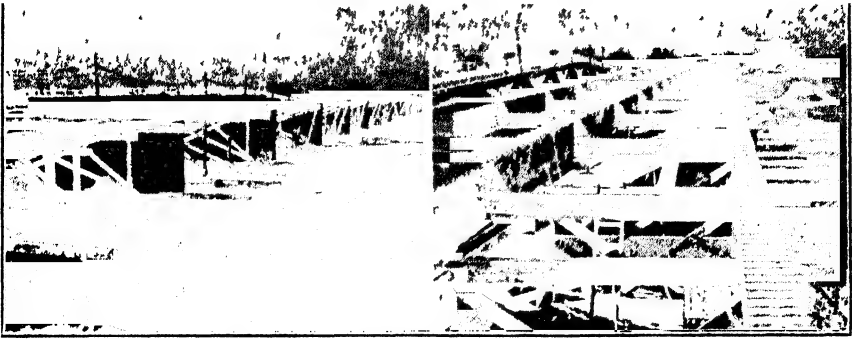
Fig. 5. (left). Structure "A", steel erection falsework. Fig. 6. (right). Structure "A", general steel arrangement.

3. Girder Splices—A butt welded field girder splice is used with the following essential characteristics:

a) A nominal 2-inch field clearance between ends of girders is provided for erection purposes

b) Ends of beams are square cut (either hot sheared at the mill or flame cut in the fabricating shop).

c) Flanges and webs are scarfed for welding. Flanges are scarfed from the top only with single Vee to permit down hand welding. Webs are scarfed from both sides for a double Vee weld

d) Filler bars of proper width are inserted into the opening, and field welded to each end of each girder.

Allowable stresses on this type of joint are 85 per cent of the full section in conformance with American Welding Society Specifications because of the single Vee flange weld. This is ample, however, as the splice is always located near the 0.25 point in the span where maximum positive or negative moments for dead plus live load rarely exceed 40 per cent of the beam strength. The advantage of down hand welding is considerable, as overhead welding from staging hung on the beam is difficult and expensive. A final overhead pass is necessary on the flanges after cleaning out the root of the first down hand pass.

The nominal 2-inch field clearance requires filler bars 1¾-inches wide, and of thicknesses equal to beam flange and web thicknesses for proper butt welding of the splice. As the nominal 2-inch clearance may vary considerably, due to mill cutting tolerances if hot sheared, and temperature at time of erection, stock lengths of bars in widths varying by ¼-inch are made available to the job, thus insuring a field welding clearance on each side of the filler bars of not greater than ⅛-inch. These bars are readily flame cut to length in the field. In the event a tapered filler bar becomes necessary due to vertical curve, camber or inaccurate beam cutting, a suitable bar can be flame cut to proper shape at the job with little trouble.

For greatest economy composite beam and girder spans should be supported at their 3rd points with temporary bents until the slab has been poured, as it permits the composite section to resist full dead load, as well as live load. It also furnishes false work for steel erection which, while not essential, is very desirable and affords opportunity to jack the beam into exact position at the splice and requires a bare minimum of splicing material for fitting up purposes.

In the two completed structures described herein, two small splice plates fastened on one side of the web, with 2 bolts in each plate were sufficient to rigidly hold the splice in position for field welding. These were removed as soon as tack welding of the filler bars was completed. The sequence of welding at a typical splice is shown in the accompanying photographs.

The contract drawings and specifications outlined general requirements to the effect that step welding was to be used and total amount of weld kept symmetrical about both axes of the beam. The welding schedule for field splices provided for welding of all splices in any one span and uniformly working from this span in both directions toward a deck expansion joint.

Temperature and shrinkage stresses in the splice during the welding process were largely eliminated by providing for a temporary sliding connection on each pier. This procedure reduced shrinkage stresses due to welding to a minimum and assured an accurate control of temperature stresses in the finished structure. Girders were welded down to the piers, only after all splices were welded, concrete deck poured, and at an average air temperature for the region.
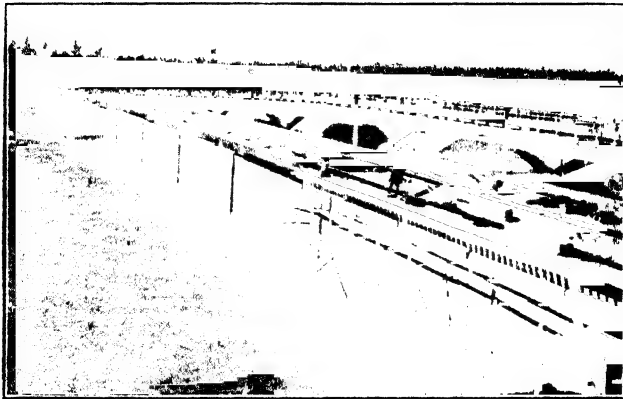
Fig. 7. Structure "A", progress view showing steel erection and concrete deck slab forms.

4. **Pier Bearings**—The pier bearing is a compact welded plate assembly using a 2½-inch wide rocker bar resting upon a base plate. The edges of the rocker are chamfered to prevent excessive edge stresses when beam rotation occurs due to deflection. This construction is much less costly than machining the rocker bar to a large radius and serves the same purpose in a practical way as the angular deflections at this joint, due to live load and temperature, are extremely small. Small keeper bars prevent lateral and longitudinal slippage and effectively transmit temperature and earthquake stresses to the pier, yet do not interfere with the hinging action of the joint for rotation.

As noted above under "Girder Splices", the pier assembly is field welded to a small beam set flush into the top of the concrete pier. This beam contains less steel, is more rigid than a base plate, requires no anchor bolts, and is therefore less costly, and more satisfactory.

The absence of anchor bolts in the welded assembly is particularly helpful during construction, as a slight misalignment in any direction is of no consequence. The bearing beams must be held to proper grade, which,
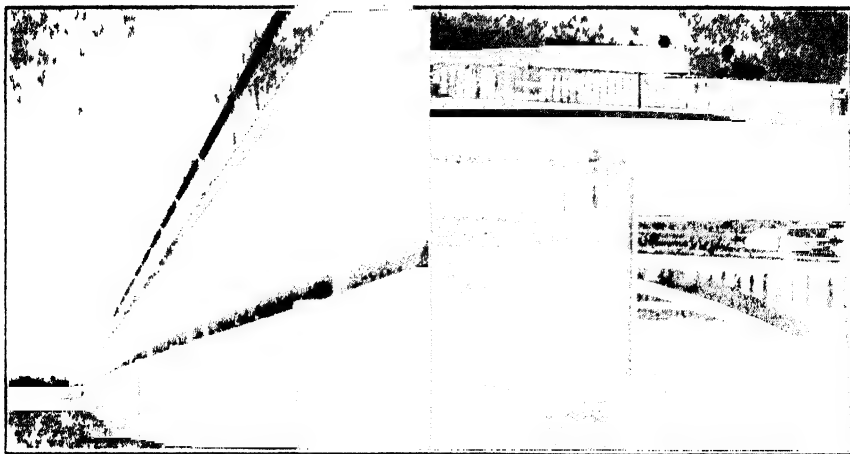
Fig. 8, (left). Structure "A", underside view. Fig. 9, (right). Structure "A", side view showing typical pier and deck details.

however, is not difficult, as the beams bolt through the top flange to cross struts directly to the pier forms

A similar bearing assembly design in riveting would involve expensive counter-sinking of rivets and in general produce a weak joint. For this reason, other types of bearings, such as a steel pin between two steel castings, have been more satisfactory than a riveted bearing The total cost of this welded bearing plate assembly is approximately 20 per cent of a steel assembly, and is distinctly more compact and better appearing.

5. **Cross Diaphragms**—Intermediate cross diaphragms between longitudinal girders in a bridge serve two purposes

(1), distribution of live loads between girders when live load is applied eccentrically to the bridge in the central portion of the span This eccentricity results in unequal girder deflections, and creates severe shearing and bending stresses in the intermediate diaphragms

(2), provides rigid edge support to the roadway slab at slab expansion joints A rigid diaphragm is very important at these locations, as the passage of live load across an open slab joint, causes high impact and a rough riding surface unless both edges of the slab are at the same elevation and rigidly supported

The all-welded diaphragm used in this design is shop fabricated from a 14-inch WF @ 30 pounds and two gusset plates, one at each end, butt welded against the beam flange parallel to the beam web

The intermediate diaphragms are erected with the 14-inch beam supported upon the bottom flange of the girders with gusset plates lap welded against stiffener plates on the girder webs. Two erection bolts are used to hold the diaphragm in position for field welding. Weld positions are arranged to eliminate overhead welding. The roadway slab does not rest upon these diaphragms, as it is important that transverse slab supports be eliminated as far as possible in the interests of a good riding surface, for reasons described earlier in this paper.

End diaphragms at expansion hinges are identical to the intermediate diaphragms, but lap under the girder top flanges, with gusset plates under-

neath. The roadway slab is supported upon these diaphragms as noted above.

The diaphragm design described herein, and shown in the accompanying illustrations has proven very satisfactory in the finished structures. The decks are noticeably more rigid than similar riveted structures under passage of live load in spite of the high ratio of length to span depth and show a marked reduction in vibration due to live load impact. While the rigidity is accomplished principally by making full use of the slab with a good type of welded shear key, the all-welded diaphragms play their part in reducing the live load impact vibration that is noticeable to a marked degree in an all-riveted span.
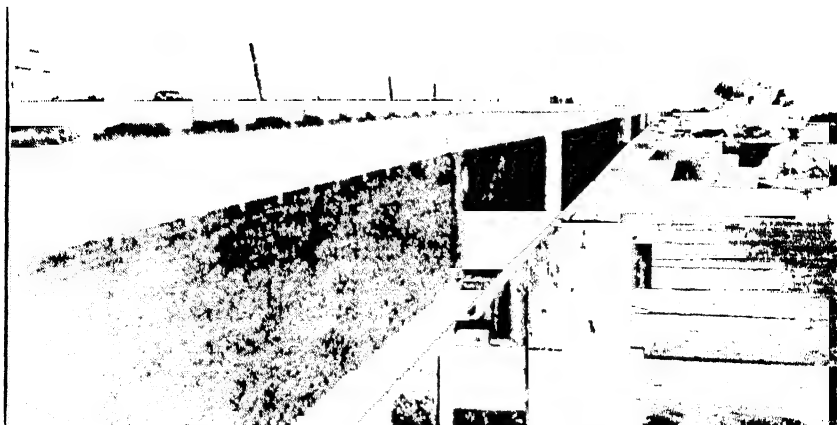
Fig. 10. Structure "A", outside girder showing completed field splice.

6. Girder Expansion Joints—Girder expansion joints, necessary to relieve temperature stresses, are located near the quarter point of a span to avoid disrupting the continuous girder arrangement. Distances between joints are dependent upon the flexibility of the concrete piers supporting the girders; which in the two structures described, were made as slender as possible and attached with a hinged connection, described earlier in the paper, to each girder.

In one of the structures described, pier heights were sufficient to permit a distance between expansion joints of 390 feet. This distance creates a total change in length of 3 inches over a 100-degree temperature range, requiring a normal joint opening of 1½-inches + 1-inch clearance, or 2½-inches.

Two tension hanger plates, suspended from a steel pin through the cantilever side of the expansion joint, support the span on the other side of the joint by a similar pin. These pins extend through the girder webs which must be reinforced with pin plates for bearing against the pin.

The pin plates are welded to the girder webs prior to boring the pin holes. As welding produces a rigid connection, in contrast to the considerable slippage necessary to cause a riveted joint to act, welded pin plates are definitely more satisfactory than the riveted for this purpose.

Lateral motion of the span beyond the expansion hinge, due to wind or seismic forces, is prevented by two small guide bars, welded on one side of
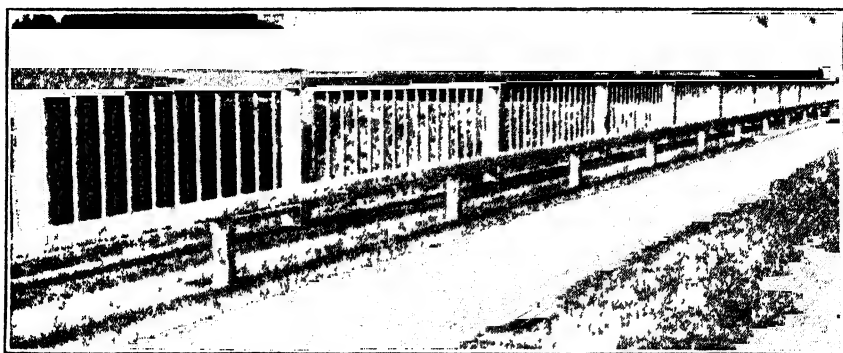
Fig. 11. Structure "A", sidewalk and railing details.

one joint to the girder flange and bearing against guide bars on this other flange. The detail is readily put together and field welded after. The girders are assembled and adjusted to line and grade.

General Data

Structure	"A"	"B"	"C"
Total length	1374′	260′	630′
Total width	35′–6″	30′–4″	30′–4″
Typical span length	61′	58′	59′–6″
Roadway width	26′	26′	26′
Sidewalks	1—5′	None	None
Structural Steel			
(a) Total weight in pounds	665,850	125,650	323,000
(b) Unit price per pound, fabrication	$0 065	$0.07	$0.0625
(c) Unit price per pound, erection	$0.02	$0.02	$0.02
Concrete (Structure)			
(a) Total volume in cubic yards	2025	410	960
(b) Unit price per cubic yard, in place	$18.50	$22.00	$18.00
Total cost of bridge	$169,920.00	$33,945.00	$83,220.00
Unit cost per square foot	$3.54	$4.30	$4.35

Shop Welding Costs

Size	Type	Speed Lineal Feet Per Hour	Electrode Pounds Per Foot of Weld	Cost in Dollars: Labor	Electrode	Power	Unit Total	Total Lineal Feet of Weld	Total Cost
5/16″	Flat	27½	0 285	.04	.03	.005	.075	7928′–0″	$594.60
3/8″	Flat	20	.37	.05	.04	.007	.097	916′–11″	88.94
½″	Flat	10	.70	.10	.08	.014	.194	303′–7″	58.89
¼″	Flat	17½	.36	.06	.04	.007	.107	143′–9″	15.38

Total Cost .... $ 757.81
Operation Factor 100% 757.81

Total 1515.62
Profit, overhead, etc.: 100% 1515.62

Total shop cost $3031.24

Field Welding Costs

Size	Type	Speed Lineal Feet Per Hour	Electrode Pounds Per Foot of Weld	Cost in Dollars — Labor	Electrode	Power	Unit Total	Total Lineal Feet of Weld	Total Cost
5/16"	Flat	27.5	.285	.05	.04	.021	.111	80'–6"	8.94
5/16"	Vert.	15.5	.325	.10	.05	.024	.174	89'–0"	15.48
3/8"	Vert.	12.	.40	.12	.06	.031	.211	497'–8"	105.01
7/16"	Vert.	9.	.58	.17	.08	.042	.292	265'–8"	77.68
5/8"	Flat	7.5	1.45	.20	.20	.10	.50	111'–2"	55.59
3/4"	Flat	6.	1.9	.25	.27	.13	.65	53'–8"	34.08
7/8"	Flat	4.8	2.15	.31	.30	.17	.78	7'–8"	5.97

Total Cost	$ 302.75
Operation Factor 100%	302.75
Total	605.50
Profit, Overhead, Etc.: 100%	605.50
Total Field Cost	$1211.00
Total Welding Cost	$4242.24
10% Contingencies	424.22
Grand Total Welding Cost	$4666.46

Shop and Field Punching, Drilling, and Riveting Costs

Note: Unit prices shown represent averages quoted by various fabricators, and include labor, materials, and all overhead costs.

	Number	Unit Price	Total
Punched Holes	70,000	$0.05	$3500.00
Drilled Holes	30,000	0.25	7500.00
Shop Riveting	32,000	0.20	6400.00
Field Riveting	7,400	0.80	7400.00
Total Shop and Field Cost			$24800.00

Note: The drilling and shop riveting required for the shear keys alone represent more than 50% of this total.

Additional Furnishing, Fabricating and Erecting Cost, Riveting Over Welding

Assume cutting, shearing and handling costs identical for both methods of fabrication.

Shop and field welding cost, as per accompanying table	$ 4666.46
Shop and field punching, drilling, and riveting costs, as per accompanying table	24800.00
Additional weight of metal, as per accompanying table	11840.00
Net Total Increase In Cost	$41306.46

Additional Weight of Metal for All-Riveted Design of Structure "A"

Location	Number	Unit Weight	Total Wt.
Girder Splices	54	@320# (average)	17,300.
Shear Keys	6700	@9.64# (net increase)	64,500.
Pier Diaphragms	46	@216# (net increase)	10,000.
Intermediate Diaphragms	96	@230# (net increase)	23,500.
Total Weight			115,300.

Net Increase in Cost Due to Weight of Metal

Additional Material Cost—115,300 lbs. @ $0.0825 (unit bid price)	$ 9,500.00
Deduct Cost of Welded Pier—69 units x 47 lbs. each @ $0.085 (unit bid price)	280.00
Additional Cost of Cast—69 units x 140 lbs. each @ $0.20 (prevailing local unit price)	2,060.00
Steel Pier Bearings	
Net total increase in cost due to weight of metal	$11,840.00
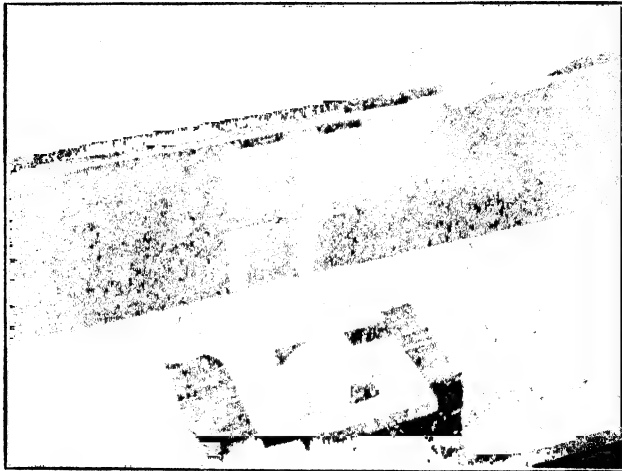
Fig. 12. Typical pier bearing assembly prior to erection.

Supporting Data for Factors of Judgment—1. Proportionate cost saving in percentage per complete unit produced by arc welding over that produced by the previous method:

Two types of savings may be demonstrated for the all welded composite steel and concrete slab highway bridge over similar or competitive types:

(1) Difference in cost between all welded and all riveted construction, both types making full use of the concrete slab as an integral part of the section.

(2) Differences in cost between all welded composite type of construction, usual riveted steel type of construction not utilizing the slab as an integral part of the section, and usual reinforced concrete tee beam and slab type of construction.

Saving (1): Total cost of Structure "A", an all welded composite design, is: $169,920. Additional cost in materials, fabrication and erection if this structure were redesigned as an all riveted composite design is $41,306.46. This represents an increase in cost of:

$$\frac{\$41,306.46}{\$169,920} = 24\%$$, or a saving of approximately 16%.

Saving (2): Unit square foot cost of Structure "A", an all welded continuous composite steel and concrete design, is $3.54. Unit square foot cost of structure "C", an ordinary riveted type of continuous steel beam and concrete slab design, not using the concrete deck slab to resist bending stresses, but similar in all other respects to structure "A", is $4.35. Unit square foot
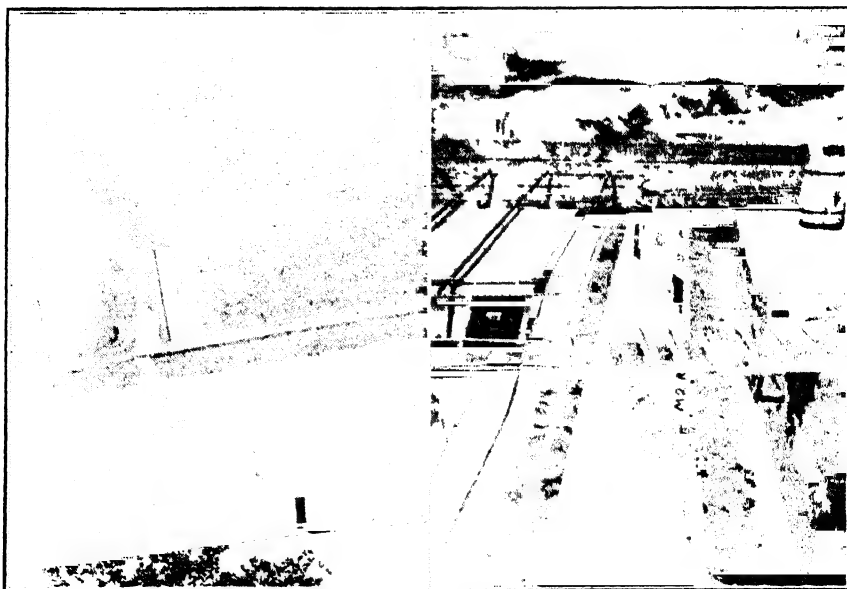
Fig. 13, (left). Structure "A", underside view of expansion joint assembly. Fig. 14, (right). Structure "B", top side view of expansion joint assembly.

cost of a typical reinforced concrete tee beam bridge, of continuous type and similar in all respects to structure "A", is $3.94, determined from actual designs and costs prepared by the writer's bridge design class in 1940 and 1941, given in evening school, and attended by members of various organizations concerned with bridge and building construction

Relative costs of structures "A" and "C" are $\frac{\$3.54}{\$4.35}$ = 76 per cent, or a saving of 24 per cent in favor of the all welded composite design.

Relative costs of structure "A" and the reinforced concrete bridge are: $\frac{\$3.54}{\$3.94}$ = 90 per cent, or a saving of 10 percent in favor of the all welded composite design.

Relative costs of structure "C" and the reinforced concrete bridge are: $\frac{\$4.35}{\$3.94}$ = 110 per cent, or a saving of approximately 10 per cent in favor of the reinforced concrete design.

2. Estimated total annual gross cost savings accruing from:

(a), use of arc welding by the company with which the author is connected in producing all structures of the type treated in the paper;

(b), use of arc welding by industry in general in producing all structures of the type treated in the paper.

Cost Saving (a)—Approximately $2,000,000 was spent by the writer's organization in the two-year period, 1940 and 1941, for construction of short-span bridges in the 40- to 80-foot span range. Of this amount, approximately three-fourths, or $1,500,000 was spent on reinforced concrete bridges. The use of all welded composite steel and concrete for all of the structures in the reinforced concrete group would have produced a saving of 10 per cent

of $1,500,000, or an annual saving of $75,000. This same type of construction substituted for the riveted steel design without composite action would have saved 24 per cent of $500,000, or an annual saving of $48,000. A total annual saving to the writer's organization of $133,000 is therefore possible

Cost Saving (b)—Written inquiries sent to all of the State Highway organizations in the United States, and to selected municipalities that had an appreciable amount of bridge construction, revealed the fact that approximately $30,000,000 was spent during the period 1940 and 1941 on bridges of all types in the 40- to 80-foot span range Construction seemed fairly equally divided between reinforced concrete and structural steel bridge types, and for purposes of this analysis may be taken as 50 per cent for each type.
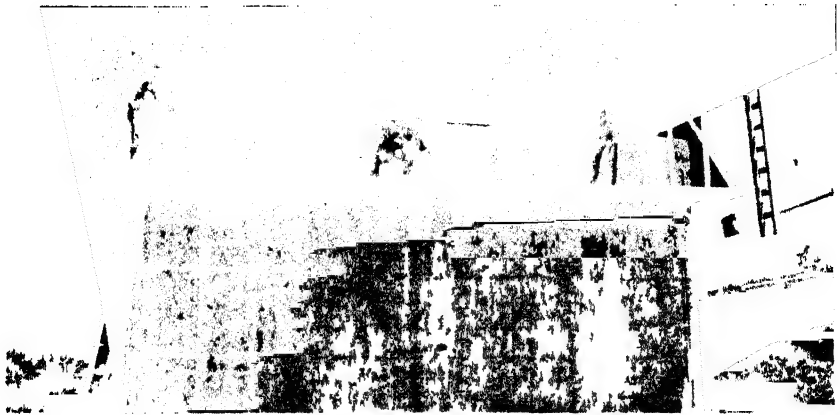
Fig. 15. Structure "A", underside view at typical pier.

A more favorable price relationship with concrete construction for structural steel exists throughout the country at large than does in the state where the writer's organization is situated, which accounts for the 3 to 1 ratio in favor of reinforced concrete in the writer's locality

Total annual savings possible, therefore, by the adoption of the all welded composite steel beam and concrete slab bridge in the short span range of 40 to 80 feet would amount to 24 per cent of $15,000,000 plus 10 per cent of $15,000,000 or a total of $2,200,000

3 Increased service life, efficiency and social advantages accruing from the use of arc welding in producing all structures of the type treated in the paper

Detailed descriptions appear in other portions of this paper to show the increased structural rigidity and better riding qualities of the bridge deck achieved through the use of all welded composite steel beam and concrete construction. These advantages are not definable in terms of cost, yet contribute measurably to a more satisfactory bridge structure from the highway users' standpoint Further, the service life of an all-welded bridge with composite slab construction is definitely greater than other structural steel types, due to the increased structural rigidity. Unfortunately, the two structures described herein have not been in operation for a long enough time to determine their maintenance cost. The writer feels, however, that they will fully justify his expectations for long and continued service.

Chapter IV—Welded Grade Separation Structure

By John F. Willis,

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John F. Willis

Subject Matter: A girder-type highway bridge, 335 feet long overall and featuring longitudinal and transverse cantilevers, with a steel super structure that consists entirely of plates and flats assembled by welding. Stirrups unite the floor slab to the girders to secure the benefit of composite action.

Handling the tremendous volume of traffic on our highways today promises to present one of the most difficult and most interesting problems which has so far confronted the highway and bridge engineers.

One very satisfactory solution, even if only partial, is the dual or four lane divided highway which is rapidly gaining popularity in almost unbelievable proportions throughout the United States.

But, in order to maintain a free and uninterrupted flow of traffic at all times it is of vital importance that all intersections, highway or railroad be separated.

Structures to perform this function range from relatively simple square bridges to elaborate long spans designed to carry one dual highway over another of the same type or a dual highway over an irregular diagonal intersection of two streets, each of which has a fairly heavy volume of traffic with which to contend at times.

Such as the latter are the prevailing conditions which necessitate the type of design described in this paper.

This structure will be one of nine, differing widely in design and type, which carry the ——— By Pass, a dual parkway connecting U. S. Route No. — with the new ——— River Bridge between ——— and ——— ——— and is the principal west approach thereto.

A site plan of the location is shown on Fig. 1, a study of which should reveal the reason for the length of span and some of the other features mentioned later.

From this plan it should be evident that Franklin Avenue, one of the main arteries leading southerly, carries the preponderance of traffic on the lower level at this intersection. Jordan Lane, east-west road, while decidedly secondary to Franklin Avenue, bears a considerable traffic load during certain periods.

Because of the irregularity of the intersection and the traffic conditions above referred to, it was decided that a single span, or at least a series of spans without an intermediate support would give the only really satis-
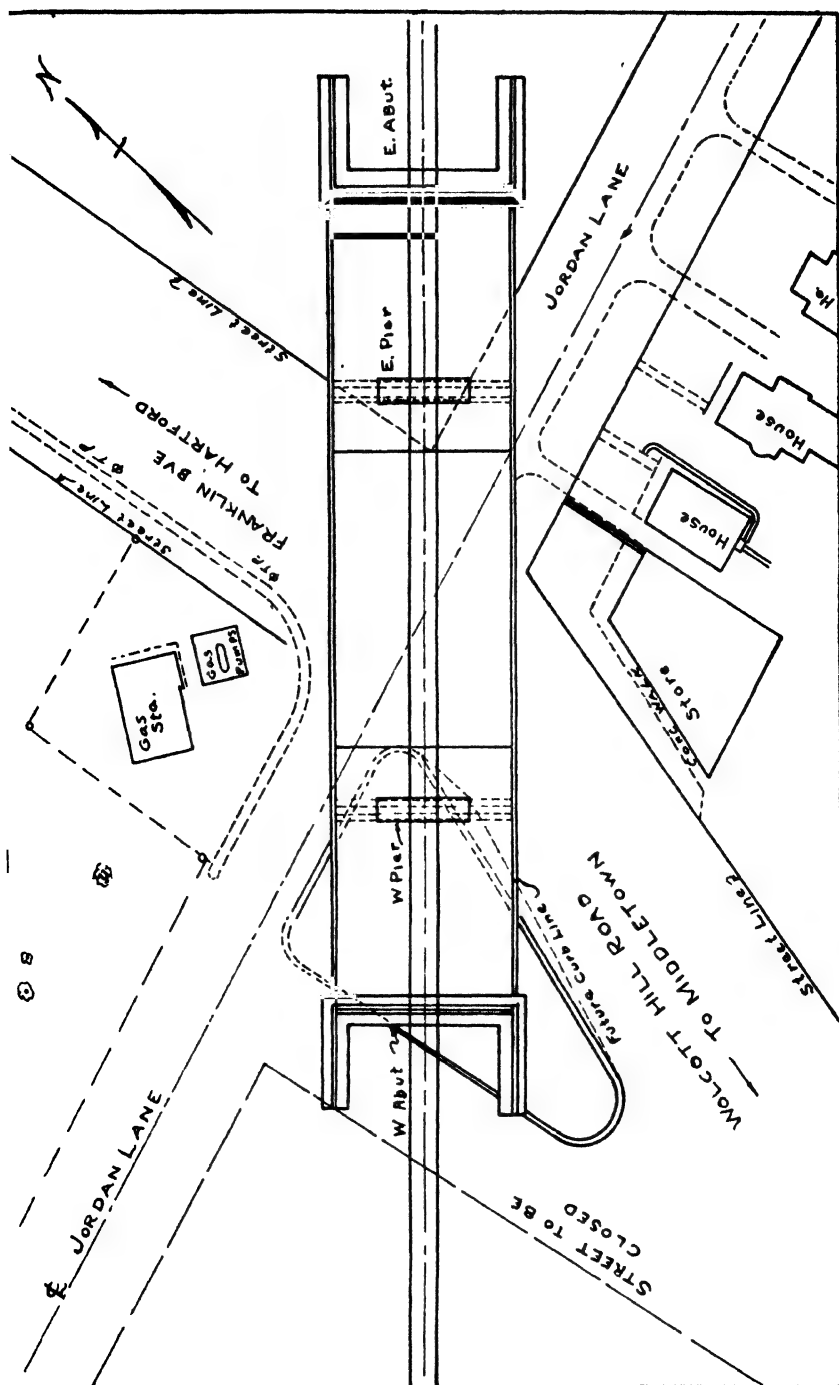
Fig. 1. Site plan of location.

factory solution, when, as always, safety is to be the item of primary consideration.

It will be noted that the total width overall is 83'-10" and because of this unusual width it was necessary to set the abutments back sufficiently far to clear all street lines. Narrower piers between the abutments shorten the clear span as shown on Fig. 2.

The suspended span and the two longitudinal cantilever spans give a total clear span of about 165 feet or 170 feet center to center of piers. As shown on Fig. 2, the structure then consists of two anchor spans of 80 feet each, two longitudinal cantilever arms or spans of 25 feet each and one suspended span of 120 feet, making a total of 330 feet center to center of end bearings or an overall length of 335 feet.

The two double cantilever arms, which, transversely to the direction of traffic, carry the overhanging remainder of the roadway beyond the piers. Owing to the extremely high bending moment in these members, they are double or of the "box" type.

The writer does not claim that the transverse steel cantilever construction would, in general construction, be the most economical, but the highway limits of the intersecting roads on the lower level precluded the use of piers of a greater width, consequently the only solution was the transverse cantilever. Had it been possible to use piers of a width equal to that of the abutments, the cost of the structure would have been greatly reduced and the erection likewise simplified, as was discovered in the preliminary investigation.

Design—There being no intricate mathematical "gymnastics" and the structure being statically determinate, the design is, for the most part, quite simple when compared to arches, frames and continuous girders of varying section.

Note—The preliminary figures from which the final span lengths of the suspended, longitudinal cantilever, anchor spans and the transverse girder spacing were derived, (many combinations were investigated) are not given here, nor are the calculations for the design of the concrete deck, nor the substructure as they are of no consequence in a paper on welded steel. The trial calculations for the steel design will not be given either, as they would be of little interest although reference to them may be frequently made.

From the accompanying sketches it will be noted that, excepting the sway bracing which is composed of angles, the entire steel superstructure consists of plates and flats and is assembled solely by arc welding.

As stated in the foregoing the arrangement was determined by the street layout and ground conditions.

The 120-foot suspended span will be first considered as the design of the remainder of the structure is dependent on the reactions from this section. However, as this span is entirely different in design from the orthodox type a brief description will be given.

In carrying out the idea of an all welded structure, the principle is extended somewhat beyond the scope of merely assembling the plates into girders. By this, reference is made to the fact that stirrups are welded to the top flanges of all the girders in this span excepting the one at the center which supports the center division.

These stirrups are designed to effectively unite the floor slab with the girder by developing the horizontal shear between these two elements, thus converting the simple steel girder into a "composite" section, similar in its action to the concrete "T" beam. The slab performs the dual function of

acting as a compression flange and also directly carrying the superimposed load and transmitting it to the other structural members

The design of this type is almost identical with the "T" beam so the same design procedure will be followed and the same nomenclature used as may be found in almost any one of the numerous textbooks on reinforced concrete

All steel properties are converted into their equivalent concrete values by the ratio of their moduli of elasticity, or, "n" = 10

Diagram, tables of section makeup, nomenclature, formulas and other details are given in Fig 3

For the purpose of determining the moments and shears, the dead and live loads are now investigated

Dead Loads—	Pounds per Lin. Ft
Slab (7″ × 5′0″) = 5 × 88	440
Haunch 1 84 + 2 33 × .33 × 150	104
Future Wearing Surface 25 lbs. per sq. ft. = 5 × 25	125
Top Flange 18″ × 5/8″ about	39
Bottom Flange 18″ × 1¼″ × $\frac{60}{120}$ about	39
Bottom Flange 18″ × ¾″ × $\frac{60}{120}$ about	23
32 Stiffeners 8″ × 5/8″ × 5′-4″ = $\frac{90\ 61 \times 32}{120}$	25
20 Stiffeners 8″ × 3/4″ × 5′-4″ = $\frac{108\ 73 \times 20}{120}$	18
Sway Bracing 6″ × 4″ × 3/8″ Ls 4′ 8″ + 4′ 8″ + 6′ 10″ = 16′ 2″ 16.17 × 10 4 × 8 (braces)	12
Web Plate 64″ × 7/16″	96
Weld Metal and Miscellaneous	29
Total	950

Max Dead Load Moment—

$$950 \times 120 \times 120 \frac{12}{8} \qquad 20{,}520{,}000 \text{ inch pounds}$$

From the viewpoint of pure theory this method of calculating the dead load moment is not strictly correct, the varying thicknesses of the lower flange plates do not give an even distribution of their weights, the weights of the stiffeners and sway braces are not distributed but are concentrated, however, the difference in the final total moment is so small, compared to the total of the sections which are of constant uniform section and weight, that it is neglected here

The live load used is what is commonly known as the "H-20", equivalent to one twenty ton truck preceded and followed by as many fifteen ton trucks as may be possible to place in each traffic lane In the simplified form this is converted into a uniform load of 640 pounds per lineal foot of each ten foot lane and a single concentration of 18,000 pounds per lane, placed at the critical point For shear the 640 pound distributed load is also used but the concentration is increased to 26,000 pounds
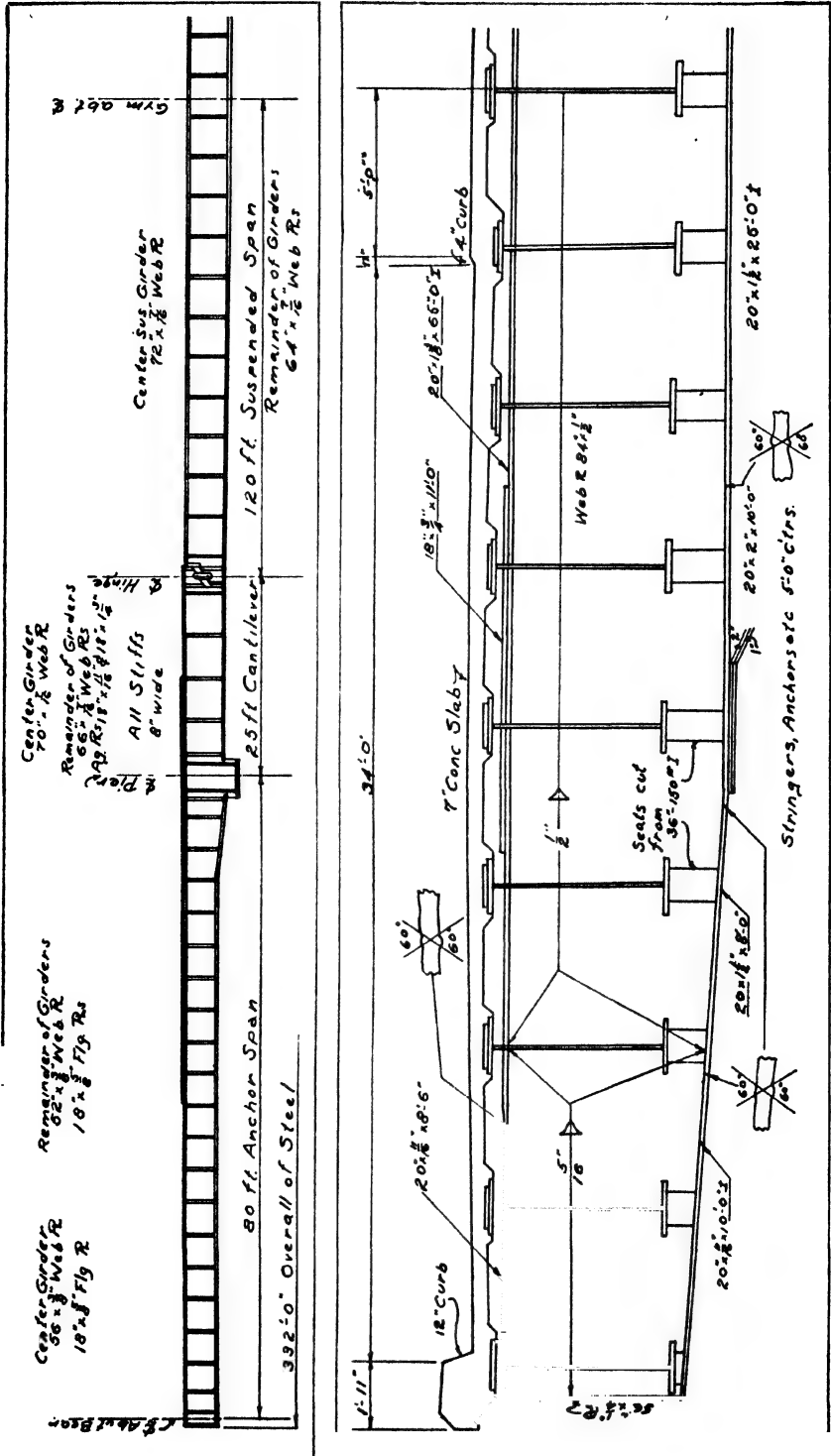
Fig. 2. (above) Half elevation. Fig. 6. (below) Half elevation transverse cantilever.

In this design the girders are on five-foot centers, therefore one half of the above loads are used.

The dynamic increment by which the live-load stresses are increased to provide for the shock or the effect of the sudden application of moving loads is based on the loaded length of structure, or in this case the span under consideration. For moment the maximum live load stresses are produced from fully loading the span while for shear the greatest stresses depend on the position of the loads.

The American Association of State Highway Officials formula for impact is used for this design and is:

$I = \frac{50}{L + 125}$, where I is the percentage of live load to be added and L is the loaded length used to produce this effect.

The bending moments, tabulated below, are given at ten foot intervals from a point ten feet from the bearing pin to the center. This was done for the purpose of investigating the possibility of a reduction of the flange areas. While the upper flange was maintained at a constant section for its entire length, the lower is spliced at the quarter points, thereby affording a substantial saving of steel, (30,335 pounds in the 16 girders).

The table of vertical shears is given (at shorter intervals, 4 feet) for conversion into horizontal shears which will be used to determine the stirrup spacing.

The moment of inertia has been calculated for the steel section and the composite at two points, the center and at the point where the section changes.

Dead Load Moments

	Foot-Pounds	Inch-Pounds
Point 10-M = (57,000 × 10) − (950 × 10 × 5)	522,500	6,270,000
Point 20-M = (57,000 × 20) − (950 × 20 × 10)	950,000	11,400,000
Point 30-M = (57,000 × 30) − (950 × 30 × 15)	1,282,500	15,390,000
Point 40-M = (57,000 × 40) − (950 × 40 × 20)	1,520,000	18,240,000
Point 50-M = (57,000 × 50) − (950 × 50 × 25)	1,662,500	19,950,000
Point 60-M = (57,000 × 60) − (950 × 60 × 30)	1,710,000	20,520,000

The uniform live load moments are $\frac{320}{950}$ of the dead load moments or 33.68 per cent and are tabulated below.

The live-load concentrated moments are calculated from the $\frac{18,000}{2}$ load described previously and are:

	Foot-Pounds	Inch-Pounds
Point 10-M = $\frac{120 - 10 \times 9,000 \times 10}{120}$	82,500	990,000
Point 20-M = $\frac{120 - 20 \times 9,000 \times 20}{120}$	150,000	1,800,000
Point 30-M = $\frac{120 - 30 \times 9,000 \times 30}{120}$	202,500	2,430,000
Point 40-M = $\frac{120 - 40 \times 9,000 \times 40}{120}$	240,000	2,880,000
Point 50-M = 120 − 50 × 9,000 × 50	262,500	3,150,000
Point 60-M = 120 − 60 × 9,000 × 60	270,000	3,240,000

Below are tabulated the bending moments as derived from the above calculations, rounded out to the nearest 10-inch pounds.

Point	D. L. Mom.	L. L. Unf. Mom.	L. L. Conc. Mom.	Impact, 21%	Total Mom.'s
10	6,270,000	2,111,736	990,000	651,365	10,023,100
20	11,400,000	3,839,520	1,800,000	1,184,300	18,223,820
30	15,390,000	5,183,352	2,430,000	1,598,804	24,602,150
40	18,240,000	6,143,232	2,880,000	1,894,879	29,158,110
50	19,950,000	6,719,160	3,150,000	2,072,524	31,891,680
60	20,520,000	6,912,000	3,240,000	2,131,920	32,803,920
					= 32,804,000

The following data relate to the diagram of Fig. 3.

Symbol	Description	0-30	30-60
b	Width of conc. compression flange	60"	60"
b'	Width of block or haunch	26" (mean)	26"
t	Thickness of compression flange	7"	7"
h	Total height of composite beam	76.875"	76.875"
d	Effective depth, C/G steel to top conc	49.58"	43.63"
d'	Height, top of steel to top of conc	11.0"	11.0"
n	Ratio of modulii of elasticity	10.0	10.0
As	Area of steel girder, sq. ins	61.75"	52.75"
Is	Moment of inertia of steel girder	43,028.89	35,067.77
kd	Distance of neutral axis from top conc	30.93"	26.60"
I	Moment of Inertia of composite Sect	1,081,556	820,352

In the following tables the dead, live load uniform, live load concentrated and impact shears are recorded. From the total vertical shears thus derived the horizontal shears are found and the spacing of stirrups to resist these shears is determined.

Vertical Shears

Point	D. L. V.	L. L. Un.	L. L. C'n	Leng. L'd	% I	Impact	Total
0	57,000	19,200	13,000	120'	21.0	6,760	95,960
4	53,200	17,940	12,570	116'	21.0	6,410	90,120
8	49,400	16,730	12,130	112'	21.0	6,060	84,320
12	45,600	15,550	11,700	108'	21.5	5,860	78,710
16	41,800	14,420	11,270	104'	22.0	5,650	73,140
20	38,000	13,330	10,830	100'	22.0	5,320	67,480
24	34,200	12,290	10,400	96'	22.5	5,110	62,000
28	30,400	11,290	9,970	92'	23.0	4,890	56,550
32	26,600	10,330	9,530	88'	23.5	4,670	51,130
36	22,800	9,410	9,100	84'	24.0	4,440	45,750
40	19,000	8,530	8,670	80'	24.5	4,210	40,410
44	15,200	7,700	8,230	76'	25.0	3,980	35,110
48	11,400	6,910	7,800	72'	25.5	3,759	29,860
52	7,600	6,170	7,370	68'	26.0	3,520	24,660
56	3,800	5,460	6,930	64'	26.5	3,280	19,470
60	....	4,800	6,500	60'	27.0	3,050	14,350

In the foregoing as in subsequent tabulations "point" refers to the distance from the zero point or the end pin. The term "Length" in all tables indicates the length loaded to produce the stress in question.

The numerical values are substituted and the solutions given for the formulas for "kd" and "I", as shown on Fig. 3.

$$kd = \frac{2 \times 10 \times 61.75 \times 49.58 + 60 \times 49}{2 \times 10 \times 61.75 + 2 \times 60 \times 7} = 30.93$$

$$\text{I—Conc. Slab} = \frac{60 \times 29{,}589.5 - (34 \times 13{,}703)}{3} = 436{,}489$$

I—Converted Steel Sect. = 10 × 43,028.89 = 430,289
I—Converted As about neut. axis = 10 × 61.75 × 346.82 214,778

Total "I" composite Sect. 1,081,556

This is for the section between points 30 and 60. By the same procedure we find that for the section between points 0 and 30,—

kd= 26.6"
I = 820,352.

The horizontal shears are now calculated and the stirrup spacing determined.

Point	Vert. Shear	Hor. Shear = H	Theo Spac = Vs/H
0	95,960	1,770	4 50"
4	90,120	1,660	4 80"
8	84,320	1,560	5.12"
12	78,710	1,450	5 51"
16	73,140	1,350	5 92"
20	67,480	1,250	6.40"
24	62,000	1,150	6 95"
28	56,500	1,050	7.60"
32	51,130	900	8.88"
36	45,750	800	10.00"
40	40,410	710	11 20"
44	35,110	620	12 90"
48	29,860	530	15.00"
52	24,660	430	18 60"
56	19,470	340	23 50"
60	14 350	250	32 00"

Theoretical spacing as indicated here is based on the use of ½ in. square bars.

Because of difficulty in obtaining some sizes, the size bar to be actually used is not known at this writing

In the above tables the horizontal shear $= \frac{\text{Vert. Shear} \times Q}{I}$, where "Q" is the statical moment of the compression slab about the Neutral axis.

For points 0 to 30	30 to 60
Q = 15,158	= 18,964
Q/I = 0.01847	= 0.01753

"Vs" in the above table is the value of a one-half inch square stirrup bar at 16,000 pounds per square inch. The bar is looped around so as to dis-

tribute the stress in the concrete and contact the top flange of the girder at two points, giving it double the value of a stirrup which is welded to the flange only once. This value is its tensile working strength or 2 x 4000 = 8,000 pounds.

The reason for using 16,000 pounds unit stress for this element when 18,000 pounds is used in all remaining steel bars or plates is to compensate for possible damage from welding a light bar.

The "Theoretical Spacing" in the table is what may be used for the average spacing of stirrups in any section between calculation points. (Please see note in Appendix with reference to this)

An inspection of the two formulas developed in the proceeding reveals that; for the moment of inertia of the composite section, the three terms embodied therein conform to the accepted criterion; that the location of the neutral axis is found precisely in the same manner as in the concrete "T" beam.

The size of sitrrups and their spacing now having been determined, the final step for this phase of the design is that of calculating the welding required to develop the full strength of the bars to be used.

While the tension in the stirrups is assumed at 16,000 pounds per square inch, the welds will be designed to develop the full 18,000 pounds stress. (This favors safety rather than economy)

If the one-half inch bar is good for a tensile stress of $\frac{18,000}{4} = 4,500$ pounds, the weld required, using ¼-inch fillets at 1,600 per linear inch, 2.81-inch or if 5/16-inch fillets at 2,000 pounds are used, 2.25 inches will be required for each end, of which two inches will be made along the sides and slightly more than one quarter inch at the ends.

The stresses in the girder or the composite member in its entirety will next be considered.

From the moment tables we find that the maximum bending moment is 32,804,000 inch-pounds. The section modulus of the concrete or compression face is, from in Fig. 3,

$$\frac{1,081,556}{30.93} = 34,967 \qquad fc = \frac{\text{Mom.}}{Sc} = 938 \text{ pounds per square inch}$$

and that for the steel or tension face is $\frac{1,081,556}{10 \times 45.945} = 2354$

$$fs = \frac{\text{Mom.}}{Ss} = 13,935 \text{ pounds per square inch}$$

(Please refer to Appendix with reference to the understress of the steel tension flange)

By the same procedure we find that the concrete stress at about point 30, the reduced section, is about 800 pounds per square inch and the steel stress is about 15,000 pounds per square inch.

The next step is to design the weld necessary to properly unite the web and flange plates. The following formula is used to determine the value "Q'" which appears:

$$Q' = Q + n \times A' \times j = 18,964 + (10 \times 11.25 \times 19.62) = 21,174$$

$$H = \frac{\text{Vert. Shear} \times Q'}{I} = \frac{95,960 \times 21,174}{1,081,556} = 1888 \text{ pounds per lineal inch}$$

From the above it is readily seen that two $\frac{5}{16}$-inch fillets are more than adequate to resist this stress.

There is but one more operation to complete the design of the suspended span girders, the design of the end pins and bearings.

The maximum end reaction is 95,960 pounds. Using a shear value of 11,000 pounds per square inch for carbon steel, the required area of the pin is 8.72 square inches which would be safely carried by 3½-inch pin. For bearing on pins subject to rotation the allowable value or working stress is 12,000 pounds per square inch which necessitates about four square inches for each link or eight square inches for the bearing area of the web. The bearing area of the latter consists of one Pl. $\frac{7}{16}$-inch web, and two pin pulleys each ½-inch thick, the bearing area of which is $1\frac{7}{16}$-inch x $3\frac{1}{2}$-inch = 5.03 square inches. Inasmuch as this is not a complete case of rotation, but somewhere between that and a stationary pin, the area of both pin and bearing are sufficient.

As previously stated, there are two one-half inch pin plates, a seven-sixteenths web plate and in addition there are two one-quarter inch spacers and two suspension links, each one inch thick. The distance cen. to cen. links is 2.9375 inches, therefore the bending moment in the pin is $\frac{95,960 \times 2.9375}{4}$ = about 70,500 inch pounds. At 27,000 pounds extreme fibre stress, a
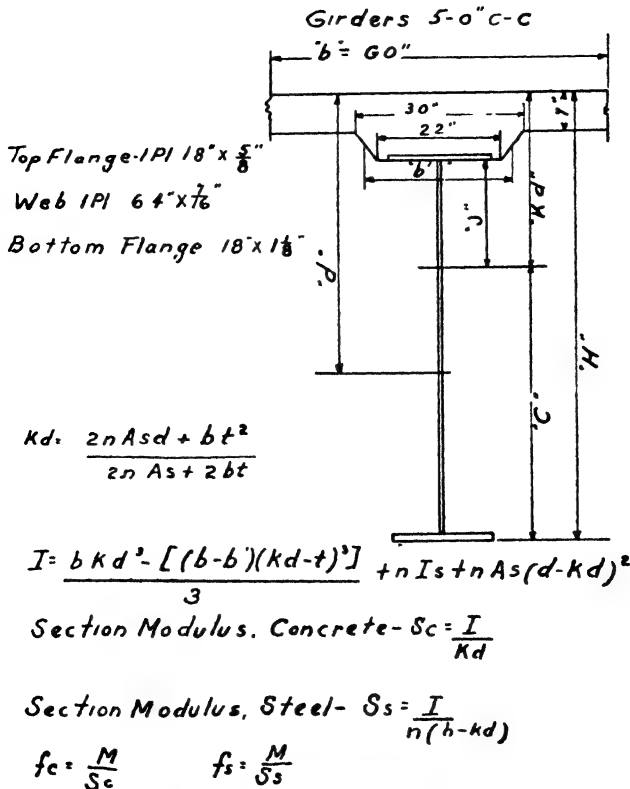
Fig. 3. Section makeup.

3½-inch diameter pin has a resisting moment of 113,600 inch pounds. It is quite evident that bearing governs. As the pin is in double shear, one-half the shear values given above should be used.

Each pin plate takes approximately one-third of the total shear, or about 32,000 pounds. Using a hole diameter of $^{13}/_{16}$-inch and a working stress of 13,600 pounds per square inch, each plug weld for attaching these plates is good for about 7,000 pounds, therefore five such plugs are required per plate.

The stiffeners are arbitrarily placed, are welded to the web and top flange and milled to bear on the tension flange.

The center girder is designed to carry the same loads as the girders under the traffic lanes with the exception of a future wearing surface of 25 pounds per square foot.

Because of the necessity of having an expansion in this superstructure, in a lateral direction and also owing to the increased height of this girder, it was not considered economical to use the composite construction.

While the 11-foot–2-inch center mall is intended to act as a traffic separation, because of the low curb it is possible that one or more heavy vehicles could travel over it, accidentally or in some possible military or other emergency. Based on this assumption, the same live and impact loads as used on the main traffic lanes will be used here.

Dead Load—Slab and haunch	500 pounds per lineal foot
Girder	290 pounds per lineal foot
	790 pounds per lineal foot

	Inch Pounds
Dead Load Mom. = 790 × 120 × 120 × 1.5	= 17,064,000
Live Load Un. Mom.	6,912,000
Live Load Con. Mom.	3,240,000
Impact	2,131,920
Total	29,347,920

Without demonstrating further, the Moment of Inertia of the steel section is 61,569 and the Section Modulus is 1,664.02.

Dividing the moment by the latter we have, fs = 17,636 pounds per square inch which is slightly below the allowable for tension in the flange. The compression flange is thoroughly imbedded in the slab so the same stress is also permitted.

As in the case of the other girders, a $^{5}/_{16}$-inch fillet weld is more than sufficient to transmit the horizontal sheer between the web and flange.

One more item concerning the suspended span which should be considered is the deflections in both the roadway and center spans.

Center Girder		Inches
"E" = 29,000,000		
"I" = 61,570		
Dead L'd D = $\frac{5 \times 94{,}800 \times 1{,}728{,}000 \times 1{,}728}{384 \times 29{,}000{,}000 \times 61{,}570}$	=	2.065
L.L.U. D = $\frac{320}{790}$ D.L.	=	.835
L.L.C. D = $\frac{9{,}000 \times 1{,}728{,}000 \times 1{,}728}{48 \times 29{,}000{,}000 \times 61{,}570}$	=	.313
Total		3.213

Roadway Girders

"E" = 2,000,000 (Concrete)........................

"I" = 1,081,556 (Composite)........................

$$\text{Dead L'd D} = \frac{5 \times 114{,}000 \times 1{,}728{,}000 \times 1{,}728}{384 \times 2{,}000{,}000 \times 1{,}081{,}556} \quad \ldots\ldots \quad 2.05$$

$$\text{L.L.U.} \quad D = \frac{320}{950}\text{ D.L.} \quad \ldots\ldots \quad .69$$

$$\text{L.L.C.} \quad D = \frac{9{,}000 \times 1{,}728{,}000 \times 1{,}728}{48 \times 2{,}000{,}000 \times 1{,}081{,}556} \quad \ldots\ldots \quad .20$$

Total.. 2.94

The center or suspended span is supported by longitudinal cantilever arms 25 feet in length, the design of which will next be considered. The calculations for the roadway cantilevers will be given only, the center girder is handled the same way and differs only in section makeup.

Dead Loads are as follows:

Top pl. 16″ × 1⅛″ × 9′–3″	23#/ft.
Top pl. 18″ × 11/16″ × 26′–6″	42#/ft.
Web pl. 66″ × 7/16″ × 23′–6″	99#/ft.
Bott. fl. pl. 18″ × 1¾″ × 12′–0″	54#/ft.
Bott. fl. pl. 18″ × 11/16″ × 10′–6″	21#/ft.
12 Stiffs. 8″ × ¾″ × 5′–6″	12#/ft.
Sway Brac.	10#/ft.
Sub-total for steel	261#/ft.
Conc. Slab (7″ × 5′–0″)	440#/ft.
Haunch	25#/ft.
Future 2″ wearing surface (5 × 25)	125#/ft.
Misc. details	49#/ft.
Total D. L./ft. cantilever	900 pounds

D.L. Mom. from above, 900 × 25 × 12.5 × 12 = 3,375,000 inch pounds

Note:—As in the suspended span, all steel members regardless of length are distributed over the entire length of the girder, except, however, as follows: at the extreme end of the cantilever there is a concentration consisting of pin plates, pins, nuts and separators, all of which weigh approximately 300 pounds, the D.L. Mom. from these is 300 × 25 × 12 = 90,000

	Inch Pounds
Total D.L. Mom.	3,465,000
L.L. Mom.–Unif. 320 × 25 × 12.5 × 12	1,200,000
Impact. Unif. 33 per cent	400,000
Mom. from sus. span incl. concentration, 96,000 × 25 × 12 =	28,800,000
Total cantilever Mom. =	33,865,000

$$\text{Allowable stress(COmp)in bottom flange} = 18{,}000 - \frac{5\,L^2}{B^2}$$

L = distance between sway bracing and B is width of flange.

$$fs = 18{,}000 - 5 \times \frac{180'' \times 180''}{18'' \times 18''} = 17{,}500 \text{ pounds per square inch}$$

Stress $= \frac{33{,}865{,}000}{67 \times 31.5} = 16{,}004$ pounds per square inch. Average over whole section.

If the upper plate is assumed to carry the full 18,000 pounds per square inch in the top chord, the resisting moment of that plate is, $18 \times 18{,}000 \times 67.5 = 21{,}870{,}000$ inch-pounds.

The remainder of the moment is then carried by the butt weld then, is:

$$\frac{33{,}865{,}000 - 21{,}870{,}000}{66.5 \times 12.37} = 14{,}580 \text{ pounds per square inch.}$$

If the stress is distributed over the entire tension section it is:

$$\frac{33{,}865{,}000}{30.37 \times 67} = 16{,}640 \text{ pounds per square inch.}$$

While the stress carried through the butt weld is about 8 per cent in excess of the usual allowable stress of 13,500 pounds per square inch for fluctuating loads, it should be noted that for several reasons the stresses have been calculated somewhat higher than is the actual case.

First,—the lever arm of all moments is taken at 25 ft. or from the center of the pier, whereas it is perfectly permissible to use the clear distance of 23-feet–6-inches. This would mean a reduction of about 6 per cent in the moments.

Second,—All dead and live loads are figured somewhat greater than what the actual case will be.

Third,—The flange stresses are calculated without consideration of any moment stress being carried by the web, which is not exactly the case. It is therefore quite reasonable to assume that the actual stresses developed on the tension flange will be on the conservative side.

The shears are now computed for determining the sizes of welds necessary to unite the flanges and webs, and webs to transverse webs.

	Pounds
Dead load of cantilever arm: 900×25	22,500
Live load on cantilever arm unif. 320×25	8,000
Impact on cantilever arm unif. 33⅓%	2,640
D.L., L.L., Conc. & Imp. from sus. span	96,000
Total Vert. Shear	129,140

Net area of web at this point............$64'' \times \frac{7}{16}'' = 28$ square inches

$\frac{129{,}140}{28} = 4{,}612$ pounds per square inch, unit shear in web.

Shear in weld connecting longitudinal web plate with web plate of transverse cantilever; at 2,000 pounds per linear inch for $\frac{5}{16}$-inch fillet $=$

$\frac{129{,}140}{2{,}000} = 64.57$ lineal inches required and as both sides of web are welded the total length is 128″, or the stress per inch is 1,008 pounds. In addition to the weld, each longitudinal cantilever rests on a saddle, consisting of a split "I" beam. This takes most of the reaction and facilitates the erection.

We next consider the welds connecting the webs to top and bottom flanges.

Moment of inertia of section, $I = 66{,}325$

Stat. Mom. of bottom flange, $Q = 608.58$

Hor. Shear $= \frac{129{,}140 \times 608.58}{66{,}325} = 1{,}184$ pounds per lineal inch

Without demonstrating further, the horizontal shear in the top flange is not much different, but owing to the thickness of the flange metal, ⅜-inch fillets are used for the first twelve feet from the transverse cantilever where the section changes, from which point to the ends 5/16-inch fillets are used.

At the point above referred to, the section consists of the web plate 66-inches x 7/16-inch as before and top and bottom flanges 18-inches x 11/16-inch.

As the new cantilever arm is now one half the former in length, the moments are one half the magnitude of those at the maximum point.

The bending moment at the half way point, as previously stated, is 33,865,000 inch pounds × ½ = 16,932,500 inch pounds.
Moment if inertia at this point is 40,000″⁴ and the section modulus is 1,127.9″³ giving a maximum flange stress of 15,012 pounds per square inch.

The reason for this understress as well as other inconsistencies is explained in the Appendix.

The minimum flange weld is used from the point under consideration to the end, is 5/16-inch fillet.

It should be noted that excepting the fillets for attaching stiffeners to web plates, regardless of stress few are smaller than 5/16″ leg.

Anchor Spans.

Balancing the longitudinal cantilever arms are the anchor spans, 80′-0″ in length from the center of end bearings to the center of the transverse cantilevers.

As in the case of all the other units of the structure the design will be carried through in detail.

Dead Load:	Pounds per Foot
Roadway Slab, as before	440
Future Wearing Surface	125
Haunch, for support of top flange only	25
Sub-total	590
Top and bottom flange pls. 18″ × 5/8″ — 2	77
Web pl. 52″ × 3/8″	67
18 stiffeners 8″ × ¾″, $\frac{20.4 \times 4.33 \times 18}{120}$	14
26 stiffeners 8″ × ⅝″, $\frac{17 \times 4.33 \times 26}{120}$	16
5 cross braces $\frac{16.17 \times 10.4 \times 5}{120}$	7
Total weight per lin. ft.	771
Use	770

It will be observed that the bending moment over the pier from the longitudinal cantilever and suspended span fully loaded is 2,822,080 feet pounds. In order to balance this, the dead load on the anchor spans must be of sufficient magnitude to produce a moment equal to or greater than that given. Assuming that the dead load is, as shown, 770 lbs. per foot, the span necessary to produce this moment or balance is:

$$WL \times \frac{L}{2} = 2{,}822{,}080 \text{ foot-pounds}$$

$$WL^2 = 5{,}644{,}150 \text{ inches}$$
$$770\,L^2 = 5{,}644{,}150 \text{ inches}$$
$$L = 85.6 \text{ feet}$$

For reasons given in the introduction and others equally sound, the span has been made 80′–0″ and the balancing moment is, therefore, 770 × 81* × 40.5 = 2,525,985 foot-pounds. This leaves a moment of 296,095′3 to be accounted for otherwise, in this case a concrete counterweight. The weight of the latter must be $\frac{296{,}095}{80}$ = 3,701 pounds. At 150 pounds per cubic foot this will require about 25 cubic feet.

The girders are 5 feet-0 inches c.-c. and the end stiffeners are on 2 foot centers, and a convenient depth for the counterweight is 3 feet 0 inches. Within the boundaries thus formed the counterweight is placed, has a volume of 30 cubic feet and weighs about 4,500 pounds.

As the economy and judgment of using a counterweight has been questioned, the writer offers the following analysis in support of his design.

Quantities and Cost of Five Feet of Extra Span, Each End.

20 L F. Bridge Railing	$12.00	$ 240.00
6,560 Lbs. Def. Steel Bars	.04	262.40
18 Cu. Yds. Concrete	14.00	252.00
35,981 Lbs. Struct. Steel	.075	2,698.57
27 Bbls. Port. Cement	2.40	64.80
Total Cost of Extra 5 ft. Each End		$3,517.77

*Span is 81′–0″ Center of pier to end.

Cost of concrete counterweights as described.

36 Cu. Yd. Concrete	$14.00	$504.00
52 Bbls. Port. Cement	2.40	124.80
2,370 Lbs. Def. Steel Bars	.04	94.80
Total cost of counterweights (32)		$723.60
Difference in favor of the latter		$2,794.17

The anchor spans are designed to provide for two different conditions of loading; first, the specifications require that after the structural steel has been erected, the concrete deck on each anchor span shall be poured first. It is possible that after this has been done much of the equipment used in the erection of the remainder of the bridge will be installed on this span. It was therefore deemed advisable to design it as a simple span, carrying the full dead and live loads, a slight reduction is made, however, because of the fact that the weight of the steel of the longitudinal cantilever arms will cause a relatively small negative moment.

The design according to this hypothesis follows:

		Pounds per foot
D.L on span		770
" " of steel of cantilever		261
Shear at pier	770 × 40	30,800

Max. Pos. Mom.

—(261 × 25 × 12.5) + 30,800 × 40 — (770 × 40 × 20)

	Inches per pound
= — 534,438 pounds per foot or	6,413,256
L.L. Unif. Mom. 320 × 80 × 80 × 1.5	3,072,000
L.L. Concentrated 9,000 × 80 × 3	2,160,000
$I = \frac{50}{80 + 125} = 24.3\%$	1,271,376
Total Pos. Mom.	12,916,632
Moment of Inertia of sect.	19,971 Inches⁴
Section Modulus " "	750 Inches³

fs = 17,222 pounds per square inch.

From the above it is evident that the section is adequate for conditions governing the first case.

Case II: Longitudinal cantilevers and suspended spans fully loaded, dead and live, dead load only on anchor span. This is a condition which can and may occur after the bridge is open to traffic.

Under full dead load on the anchor and longitudinal cantilever spans, the point of contraflexure is located about 8 feet (7.2 feet exact) from center of the pier, toward the abutment.

For the purpose of calculating the dead load moments from the parabolic curve, the remaining 72 feet are divided into 10 equal parts of 7.2 feet each. At the same points the negative moments from the conditions described previously are calculated. (The dead load moments are positive.) The algebraic sums of the two are tabulated, which now becomes the net negative moments on which to base this part of the design. In the tables given below, the moments and all other data necessary for the design are recorded.

The additional section necessary for the excess of negative over positive moments is provided by the extension of the heavy cover plates at and adjacent the transverse cantilever. At the point where the outer cover plate can be reduced but additional flange area is necessary a smaller plate is added, (16″ × ½″) by butt welding to the heavier plate and then to the flange plate. To augment the section at the butt joint which is calculated at 13,500 pounds per square inch, two plates, 6 inches x ⅝-inch are welded under the upper joint and over the lower joint.

It is only necessary to carry the extra cover plates to a point near the center of the span, from there to the abutment and the section is of sufficient area for the moments involved.

From the point of contraflexure to the pier end of the girder, the web thickness is increased from ⅜-inch to 7/16-inch, not because of the shear but to comply with the $\frac{\text{"d"}}{}$ ratio maximum of 170.

Fig. 4. Details of anchor span and longitudinal cantilever span.

Moments in Anchor Span

Point	Neg. Mom.	Pos. Mom.	Net Mom.	"s" Req'd
7.2	3,047,840	2,169,555	878,285	48.8
14.4	6,095,680	3,856,988	2,238,692	124.3
21.6	9,143,520	5,062,296	4,081,224	226.7
28.8	12,191,360	5,785,482	6,405,878	355.8
36.0	15,239,200	6,026,544	9,212,656	511.8
43.2	18,287,040	5,785,482	12,501,558	694.5
50.4	21,334,880	5,062,296	16,272,584	904.03
57.6	24,382,720	3,856,988	20,525,732	1,140.3
64.8	27,430,560	2,169,555	25,261,000	1,403.3
72 0	30,478,400	....	30,478,400	1,693.2

From the above table it is evident that the section modulus of the anchor span, 891.7 cubic inches, is adequate without additional cover plates from the abutment to a point near the center. From this point to the pier additional cover plates are added as previously described.

While a 5/16-inch fillet weld is ample to transmit the horizontal shear from the web to the flange, the size is increased to 3/8-inch because of the fact that a reversal of stress will occur under various loading conditions.

Details of this portion of the structure are shown in Fig. 5.

Transverse Cantilevers

In the design of these members, the procedure of calculating loads is somewhat the reverse of that used in the preceding text.

In designing the suspended span, longitudinal cantilevers and the anchor spans, the weights or dead loads were distributed in order to consider them as uniform per foot loads.

Because of the high concentrations from the anchor, longitudinal cantilevers and suspended spans, the five foot intervals of the transverse girders are also considered as concentrated. This simplified the moment calculations and whatever error is present is on the safe side.

The moments and shears will be calculated at each concentration point and between where necessary, but after this has been done the subsequent tabulations will be based on one-half of the values thus obtained. This is to simplify calculations for section modulus etc. Each half of the box girder is therefore considered as taking its proportionate part of the load.

The maximum stresses outside the limits of the piers will occur with this section fully loaded. In the center section a positive moment of considerable magnitude may be obtained by applying the live load only to that area. This is a possible but highly improbable condition of loading because of the center dividing strip seldom being occupied.

The actual concentrations as derived from the anchor, suspended and longitudinal cantilever spans will be considered first.

Anchor Spans,—

	Pounds per foot
Dead Load	800
Live "	320
Impact	60
Total	**1,180 use 1,200**

$kl = .238$

$R = \frac{wl}{2(1-kl)} = \frac{1{,}200 \times 105}{2 \times .762} =$ 82,680

R — from suspended span $= \frac{96{,}000 \times 105}{80} =$ 126,000

208,680 pounds

Excess of cantilever over anchor = 100 pounds per foot

R — = 100 × 25 2,500

Subtotal for all points 211,180 pounds

In calculating the dead loads of the transverse girders, the diaphragms, the compression struts inside and the web plates are of practically the constant weight, but, although the flanges vary to a considerable extent in thickness, their total weight distributed, then concentrated at the load points will give moments and shears differing so slightly from the actual cases that further refinement of calculation is not necessary.

From a breakdown of quantities we find that one complete box girder weighs 87,400 pounds. Divided by its length, 82 feet, the weight per foot is 1,066 pounds or 5,330 pounds at each concentration point.

The total assumed concentrated load at each point then is, 216,510 pounds.

The moments over the bearings and at intervals toward the outer ends will be shown. The distance of the origin of moments for each case will be designated by 0, 5, 10, etc.

Note: The heavy railing, massive curb and parapet, together with the heavy castings used in the ornamentation will practically compensate in weight for the fact that the outer girder carries only one-half panel of floor.

Transverse Cantilever Moments

Point	Calculation	Inches per pound
0	—216,510 × (5 + 10 + 15 + 20) × 12	= 129,906,000
5	—216,510 × (5 + 10 + 15) × 12	= 77,943,600
10	—216,510 × (5 + 10) × 12	= 38,971,800
12.5	—216,510 × (2.5 + 7.5) × 12	= 25,981,200
15	—216,510 × 5 × 12	= 12,990,600

Inasmuch as this is a double box girder the diaphragms are designed to equalize the loads between the two sections of the girders. Calculations from here on deal with one-half the loads, stresses and sections.

From the following table it will be seen that at points 5 and 10 the flange section could have been reduced, but, at the "0" point where the stress is greatest, only a slight reduction could have been made.

At the two points, 15 and 20 foot respectively from the origin, the flange thickness is governed by the $\frac{\text{"b"}}{t}$ limits as in like manner the web thickness is governed by the $\frac{\text{"h"}}{t}$ ratio (170) for carbon steel, not by the stress except at the point nearest the bearing.

Reduced Moments and Section Data

Point	Mom. Reduced	S-Required	S-Used
0	64,963,000	3,609.06	3,923.0
5	38,971,800	2,165.1	2,797.7
10	19,485,900	1,082.5	2,460.5
12.5	12,990,600	721.7	1,473.8
15	6,495,300	360.8	1,373.7
20	....	....	1,373.7

Investigating the 40 foot section between the bearing points, we find that an appreciable reduction in flange area is possible because of the positive moment developed.

The critical condition of loading for negative moment is produced when the live load is applied on the cantilever section of the girder only and the dead load only is present on the section between bearings.

The positive moment caused by this dead load, however, is sufficient to permit a reduction in the flange plates to a single plate 20 inches x 1⅜-inches as against this plate plus an 18 inch x ¾-inch plate. This reduced section is effective for a distance of 25 feet.

The design of this section is as follows: The total dead, live and impact reaction at each load point, from the foregoing, 216,510 pounds, gross, or 108,255 pounds for each half of the box girder. The dead load concentration alone is about 69,600 pounds.

Max. Neg. Mom. from cantilever ....5,413,580 foot pounds
" Shear, inside section, 69,600 × 4 .... 278,400 pounds

In the following tabulation the points designated by 5, 10, 15 and 20 refer to the distance from the bearing, this time inside or between the bearings.

Interior Moments, Minimum (Max.—)

	Inches per pound
5—5,413,580+278,400× 5 × 12	—48,258,960
10—5,413,580+278,400×10 — 69,600×5×12	—35,730,960
15—5,413,580+278,400×15 — 69,600×(5+10)×12	—27,366,960
20—5,413,580+278,400×20 — 69,600×(5+10+15)×12	—23,202,960

Loading the center section, live, and leaving the cantilevers unloaded will yield the maximum positive moments.

Max. Neg. Mom. 69,600×(5+10+15+20)............3,480,000 foot pounds
" Shear, inside, 108,255×4.................................. 433,020 pounds

Interior Moments, Maximum (Max.+)

	Inches per pound
5—3,480,000+433,020× 5×12	—15,778,800
10—3,480,000+433,020×10×108,255×5 ×12	+ 3,707,100
15—3,480,000+433,020×15 — 108,255×(5+10)	+16,637,700
20—3,480,000+433,020×20 — 108,255×(5+10+15)	+23,193,000

From the foregoing tables it is evident that under the loading conditions specified, the maximum negative or positive moments, depending on the manner of loading, are about equal.

While it is possible to make additional reductions in the flange plates

as was done for a length of 25 feet, it would not be in the interest of economy to make a second splice on the inside as the cost of two per side or a total of eight would exceed the value of the steel saved.

It will be noted that in the splices of the compression flange of the transverse girders a straight across butt weld is used, while all tension splices are accomplished with an extended "V" weld, as shown on Fig. 6.

If we assume the value of a tension weld at the most conservative figure of 12,000 pounds per square inch, it logically follows that by increasing the length of the weld 50 per cent, the strength equivalent to that of the solid metal will be attained.

In the design of this structure, a value of 13,500 pounds per square inch has been used for tension butt welds, as well as compression, where fluctuating stresses are present. The values of fillets in shear are given elsewhere in this paper.

The specifications for this project require that all plates which are to be spliced shall be so done before assembling. Thus all spliced girder flanges are welded together before being welded to the girder webs, thereby reducing or eliminating stresses "locked up" due to shrinkage.

The splices required to unite the longitudinal cantilevers with the anchor girders, however, cannot be done this way because of necessity these are field splices.

Cost Analysis—In analyzing the cost of the structure, first consideration will be given the weight of electrode or weld metal used.

The specifications require that all structural steel shall conform to the requirements of American Society for Testing materials, Serial Designation, A-7 or A-10.

The electrode used shall be "Semi-Slag, Shielded", meeting the requirements of the A.W.S.-A.S.T.M. of Grade 10 or Grade 15 for filler metal.

The quantity of welding rod used in these figures is based on the actual amount which shall include all loss from excess spatter and the short ends, which although not used are included in the gross weight to be paid for. Any salvage value of this material is not considered here.

The method of calculation here used is based on data furnished by one of the largest structural steel companies in the world.

The weight of weld metal to be paid for will be somewhat less than these quantities.

Weights of Weld Metal

Stiffeners—Owing to the fact that each stiffener has a 1-inch x 1-inch triangle cut the two inside corners to allow for continuity of the welds uniting web and flange, fillet welds for attaching the stiffeners to the webs are shortened by this amount or one-half the perimeter minus three inches will be the actual length for each side.

Intermediate stiffeners are welded to the compression flange only and are milled to bear on the tension flange. The end stiffeners are welded all around.

On suspended spans—Each intermediate stiffener of this span excepting those on the center girder will have a total length of weld fillet of $(64+8)-3=69$ inches per side, or 138 inches 11.5 feet per stiffener.

There are 16 of these girders on each of which there are 52 stiffeners.

Total length of these $\frac{5}{16}$-inch fillets, $11.5 \times 52 \times 16 = 9{,}568$ feet.

For the center girder with its 72 inch web plate, the length of weld will

be, (72+8)—3=77 inches per side or 154 inches 12.8 feet per stiffener.

Length of fillet, 52 x 12.8=666 feet.

End stiffeners. Short, 34 pieces, double width, 2 fillets each side full length and welded to both flanges, fillets 2 feet, all girders about same.

Total length, 4 x 8 + 2 x 24=80 inches or 6.67 feet per end per girder.

Total length, all short stiffeners, 6.67 x 34=227 feet.

Total length all stiffener welds—10,461 feet.

Weight of above .333 pounds per foot, 10,461 x .333=3.484 pounds.

On anchor spans—32 girders, outside, 38 regular length stiffeners (52 X 8)—3=57 inches one side, 114 inches both sides or 9.5 feet per stiffener. Total length of welds on regular (52 inch) stiffeners=9.5 x 32 x 38=11,552 feet.

6 stiffeners per girder, average length 59 inches, (59+8)—3=64 inches 128 inches or 10.67 feet per stiffener. Total length of these is, 10.67 x 6 x 16=1,025 feet.

Center anchors—56 inch web at normal. Length fillet=(56+8)—3=61 inches one side or 122 inches—10.17 feet both sides.

Total length 10.17 x 38 x 2=773 feet.

6 stiffeners per girder averaging 63 inches longitudinal length fillets is (63+8)—3=68 inches one side or 136 inches—11.33 feet both sides.

Total length 11.33 x 6 x 2=136 feet.

Total length of fillets in all anchor spans—13,486 feet.

Weight of above—13.486 x .333=4,491 pounds.

On longitudinal cantilevers—There are 12 full length stiffeners on each of these members which have 66 inch web plates. (All but the center girder.)

Length fillet on above (66+8)—3=71 inches one side or 142 inches both sides,—11.84 feet per stiffener.

Total length of fillets, 11.84 x 6 x 32=2,274 feet.

On center cantilevers, 70-inch web plates length fillets (70+8)—3=75 inches one side or 150 inches—12.5 feet both sides.

Total length fillets 12.5 x 6 x 2=150 feet.

The short stiffeners at the ends of these cantilevers are all the same and are about equal in length to the corresponding plates on the suspended spans. Total length is 227 feet.

Total length of fillets for all longitudinal cantilevers is 2,651 feet.

Total weight of weld metal in above,—2,651 x .333=8,858 pounds.

On each "Z" or diaphragm assembly there are 120 inches or 10 feet of $\frac{5}{16}$-inch fillets. There are 352 of these diaphragms which require 3,520 lineal feet of welding.

The total weight of this metal is, 3,520 x .333=1,173 pounds.

There are 64 angles at the ends of the anchor spans for the support of the end diaphragms which are of concrete. (Previously described as counter-weights.)

Each is 2 feet long and is attached with 2$\frac{5}{16}$-inch fillets for the full length.

Total length of this weld is, 64 x 2 x 2=256 feet.

Weight of above 256 x .333=86 pounds.

Between the two webs of each box girder there are 17 diaphragms, composed of plates 36 inches x 1 inch. Nine of these are 7 feet, 0 inches long and the remaining eight are an average of 6 feet, 6 inches in length. Each of these is attached to the webs of box girders by four $\frac{3}{8}$-inch fillets, full length. Length, all fillets is (7 x 4 x 9) + (6.5 x 4 x 8) x 2 = 920 feet.

Weight of above at .45 pounds per foot is 920 x .45 = 414 pounds.

There are 68 compression struts near the lower ends of the diaphragms consisting of half 12-inch Is, each of which requires 116 inches or 9.67 feet of 5/16-inch fillet weld. (These are also milled for exact fit.)

Length of above fillets, 9.67 x 68 = 658 feet.

Weight of above 658 x .333 = 220 pounds.

There are 68 girder seats consisting of partial or "T" sections of 36-inch-150-pound I beams, each of which is welded to the main girder. The average length of these seats is 1.53 feet. The webs of these are shop welded to the webs of the main girders and the 12-inch flange is shop welded to the bottom flange of main girders, all with 5/16-inch fillets.

The length of weld for each seat is, 2 x 1.53 + 1.0 = 4.06 feet per seat. Total length of above is, 4.06 x 68 = 276 feet.

Weight of above, 276 x .333 = 92 pounds.

The main transverse girders are welded to the sole plates (48 inches x 2 inches x 5 feet 6 inches) with one-half inch fillets.

The total length of fillets for two bearings per sole plate, two sole plates per girder and two girders, is 48 x 4 x 2 x 2 = 768 inches or 64 feet.

Weight of above at .75 pounds per foot, is, 64 x .75 = 48 pounds.

Bottom laterals, consisting of 5 inches x 3½ inches x 3/8-inch angles, installed on either side of each pier on the anchor and longitudinal cantilever spans.

The quantity of welding is determined by the number of contacts these angles make with the above mentioned girders and the length of fillet at each contact.

These laterals are in "X" form and are placed as follows:

1- "X" each side center, anchor spans.

1- "X" each side center, cantilever spans.

Total, 8- "X"s each having 16 angles.

Total, 128 angles each having two contacts or 256 contacts.

Each contact is 2 feet, 0 inches long.

Total length of above fillets (5/16-inch) = 256 x 2 = 512 feet.

Weight of above 512 x .333 = 171 pounds.

Pin Plates

There are two of these plates at the ends of each suspended girder and two at the end of each longitudinal cantilever. The total number of plates then is, 17 x 4 x 2 = 136.

The perimeter of each plate is 12 feet, 8 inches.

Total length of fillets for these—136 x 12.67 = 1,724 feet.

Attached with ¼-inch fillets, the weight of above at .22 per foot is, 1,724 x .22 = 380 pounds.

Each of these ½-inch plates is further attached with 5 plug welds, 13/16-inch diameter x ½-inch. The weight of weld metal used for these is, at .113 pounds each is 136 x 5 x .113 = 77 pounds.

Flange to Web Welding

On suspended Span—Top length 117 feet, 8 inches.

Total length all, 117.67 x 2 x 17 = 4,000 feet.

Bottom, 62 feet.

Total length, bottom fillets, 2 x 31 x 2 x 17 = 2,108 feet.

Total of all above using 5/16-inch fillet, 6,108 feet.

Weight of above, 6,108 x .333 = 2,034 pounds.

For center 60 feet using ⅜-inch fillets at .45 pound per foot.
Length—60 x 2 x 17 = 2,034 feet.
Weight of above, 2,034 x .45 = 918 pounds.
On transverse girders,—
Top and bottom, center section, length 60 feet using ½-inch fillets at .75 pounds per foot.
Total length 60 x 8 x 2 = 960 feet.
Weight above, 960 x .75 = 720 pounds.
Top and bottom, outside sections, length 20 feet each using 5/16-inch fillet at .333 pounds per foot.
Total length 20 x 8 x 2 x 2 = 640 feet.
Weight of above, 214 pounds.
On anchor spans. All ⅜-inch fillets at .45 pounds per foot.
Top flange, length 78 feet, 3 inches.
Total length, all, 78.25 x 34 x 2 = 5,321 feet.
Bottom flange, length 79 feet, 6 inches.
Total length, all 79.5 x 34 x2 = 5,406 feet.
Total all welds in anchor spans, 10,727 feet.
Weight of above, 10,727 x .45 = 4,828 pounds.
On longitudinal cantilevers. All ⅜-inch fillets.
Length, top 23 feet, 3 inches.
Length, bottom 22 feet, 4 inches.
Total per girder 55 feet, 7 inches.
Total length, 55.58 x 34 x 2 = 3,780 feet.
Weight above, 1,701 pounds.
Welding anchors and cantilevers to transverse girders.
Center girders, 5.5 feet per connection—4 connections.
Length, 5.5 x 4 x 2 = 44 feet.
All other girders, 5.0 feet per connection—64 connections.
Total length, including center, 64 x 5 x 2 = 640 + 44 = 684 feet.
Bottom flange to flange of seats, at one foot each 1 x 68 = 68 feet.
Total, all above welds, 708 feet.
Weight of above, 5/16-inch fillets at .333 pounds per foot, 708 x .333 = 236 pounds.
Butt welds, suspended spans, two for each flange, each girder.
Bottom flange, width of flange 18 inches horizontal "V" splice designed for at least 150 per cent of width or 27 inches or 2.25 feet.
Total length 17 x 2 x 2.25 = 77 feet.
⅝-inch plate at splice point, weight metal, 1.4 pounds per foot.
Weight of above, 77 x 1.4 = 109 pounds.
Top flange, 18 inches x ⅝-inch—2 splices straight across.
Total length, 17 x 2 x 1.5 = 51 feet.
Weight of above, 51 x 1.4 = 72 pounds.
All of above splices are cut on a double "V" in section.
Butt welds for girder webs, suspended spans. (1.25 pounds per foot.)
One each girder, web plates, 64 inches x 7/16-inch outside 16.
One each girder, web plates, 72 inches x 7/16-inch center 1.
Total length, 5.33 x 16 + 6.0 = 92 feet.
Weight above, 92 x 1.25 = 115 pounds.
Butt welds for anchor spans, web plates 52 inches x ⅜-inch outside 32.
Butt welds for anchor spans, web plates 56 inches x ⅜-inch center 1.
Total length, 4.33 x 32 + 4.67 x 2 = 148 feet.
Weight of above at 1.05 pounds per foot, 148 x 105 = 156 pounds.

Lower flange splices, anchor spans, all straight across.

First—18 inches x ⅝-inch plate at bottom plate (Double "V")

Total length, 34 x 1.5 = 51 feet.

Weight above, 51 x 1.4 = 72 pounds.

Second—16 inches x ½-inch plates under bottom flange plate (Single "V").

Total length, 34 x 1.33 = 46 feet.

Weight above at 1.5 pounds per foot, 46 x 1.5 = 69 pounds.

Upper flange (anchors).

Butt over transverse girder, 18 inches x ⅝-inch plate, single "V" fillet, straight across.

Total length, 34 x 1.5 = 51 feet.

Weight above, at 2.1 pounds per foot, 51 x 2.1 = 107 pounds.

Butt welds, end of top cover plate to 16 inches x ½-inch cover on anchor, (Single "V").

Total length, 34 x 1.33 = 46 feet.

Weight above, at 1.5 pounds per foot, 46 x 1.5 = 69 pounds.

Fillet weld, lower flange cover plate.

Length plate 30 feet, length fillet 60 feet, 6 inches, 5/16-inch fillet.

Total length, 60.5 x 34 = 2,057 feet.

Weight above, 2,057 x .333 = 685 pounds.

Fillet weld, upper flange cover plate, length plate 32 feet, 0 inches, length fillet 64 feet, 6 inch, (5/16).

Total length, 64 x 34 = 2,193 feet.

Weight above, 2,193 x .333 = 731 pounds.

Fillet welds, plate joining longitudinal cantilever and anchor spans over transverse girder, plate, 16 inches x 1⅛-inch x 19 feet, 8 inches, length fillet 39 feet, 8 inches (⅜-inch fillets).

Total length, 39.67 x .45 = 1,349 feet.

Weight above, 1,349 x .45 = 607 pounds.

There are 36 cast iron ornaments, each of which is attached to the outside girders by 6 inch channels 4 feet, 6 inches long. Each channel requires 1 foot of ¼-inch fillet.

Total length, 36 x 4 x 1 = 144 feet.

Weight above, 48 x .22 = 11 pounds.

Welding sole plates to anchor spans. Plates, 24 inches x 12 x 2 feet, 0 inches (⅜-inch fillets).

Length fillet, each plate 48 inches.

Total length, 34 x 4 = 136 feet.

Weight above, at .45 pounds per foot, 62 pounds.

48 inches x ¼-inch x 6 feet, 0 inches plates, ends transverse cantilevers, attached by two ¼-inch fillets.

6 feet, 0 inches long. Total weight, 6 x 2 x 4 x .22 = 11 pounds.

Total length, 48 feet.

Gross weight of all weld metal (electrodes), 23,536 pounds.

In this analysis the weld metal to be included in the determination of the cost is that used for the shop welding only. The electrode required for field welding is accounted for in a different manner as will be subsequently explained.

From the above total, then, the metal in the following items should be deducted:

	Pounds
Diaphragms or "Z" frames	1,173
Bottom laterals	171
Anchor and cantilever connections to main girders	236
Butt welds over transverse girders, anchor to cantilever	107
Butt welds top anchor to cover plate	69
Fillet welds on top anchor and cantilever cover plate	607
Total weight of electrode for field welding	2,363

Deducting this amount from the total given above, there remains 21,173 pounds to be included in the amount charged to the total cost of the structural steel.

Flame Cutting Costs—In estimating the above costs, the following data will be used:

	Per Hour
Operator, cutting or arc welder,	$1.50
Comp. Insurance, 10 per cent	.15
Idle time, operator resting, and during manipulation, 25 per cent	.41 (of tot.)
Total cost per hour per operator,	$2.06

From various inquiries the writer learns that the manipulation costs of material, that is, the cost of placing in position for cutting and/or welding should not exceed $0.005 for each operation and this figure will be used.

The item of field welding is handled differently from that of shop, because of the fact that all of this work is (or was) performed by a commercial weldery, an outfit which furnished an operator and all equipment and materials for $36 per day of eight hours.

For this reason the quantity of shielded electrode will not be included in estimating the cost of field welding. This quantity is given only to show the amount "Industry" benefits by the project.

Cutting speed and costs, at $2.06 per hour for labor and gas as shown.

Foot per Hour	Thickness	Labor Cost	Gas Cost	Total per Foot
120	¼"	$0.0173	$0.02	$0.0373
110	⅜"	0.0173	0.02	0.0373
108	7/16"	0.0189	0.02	0.0389
107	½"	0.0189	0.03	0.0489
100	⅝"	0.0206	0.03	0.0506
100	11/16"	0.0207	0.04	0.0607
90	¾"	0.0228	0.04	0.0628
85	1"	0.0243	0.045	0.0688
75	1⅛"	0.0274	0.05	0.0774
65	1¼"	0.0317	0.055	0.0867
55	1½"	0.0375	0.06	0.0975
45	2"	0.0458	0.075	0.1208

Part	No. Pieces	Size	Length per Cut	Length all Cuts	Cost per Foot	Total Cost	Location
Sol. pl.	34	1"	2.0'	68'	$0.0688	$4.6784	On abut.
Mas. pl.	34	1"	2.0'	68'	.0688	4.6784	On abut.
Fl. pls.	34	5/8"	1.5'	51'	.0506	2.5805	Anchor, top
Fl. pls.	34	5/8"	1.5'	51'	.0506	2.5805	Anchor, bottom
Cov. pls.	34	1/2"	1.33'	46'	.0489	2.2494	Anchor, top
Cov. pls.	34	1/2"	1.33'	46'	.0489	2.2494	Anchor, bottom
Fl. pls.	34	1 3/4"	1.5'	51'	.1208	6.1608	Anchor, bottom
Spl. pls.	34	1 1/8"	1.33'	46'	.0774	3.5604	Over trans. girder
Spl. pls.	34	1 1/8"	9.33'	317'	.0774	24.5358	Over trans. gird. diag.
Anchor	34	7/16"	9.75'	332'	.0389	12.9148	Diag., bottom web
Trs. gd.	4	1/2"	7.0'	28'	.0489	1.3692	Web pls.
Trs. gd.	34	1"	3.0'	102'	.0688	7.0176	Diaphragms
Trs. gd.	34	1"	3.0'	102'	.0688	7.0176	Comp. strut. web
Trs. gd.	34	1 3/4"	2.33'	80'	.1208	9.664	Comp. strut. flanges
Trs. gd.	34	5/8"	2.33'	80'	.0506	4.048	Web for seats
Trs. gd.	34	1"	2.0'	68'	.0688	4.6784	Flange seats
Trs. gd.	4	1/4"	4.67'	19'	.0373	.7087	End pls., trans. gird.
Trs. gd.	16	11/16"	1.67'	27'	.0607	1.6362	Top flange
Trs. gd.	4	1 3/8"	1.67'	7'	.090	0.630	Top flange cover
Trs. gd.	8	3/4"	1.5'	12'	.0628	0.7536	Top flange cover
Trs. gd.	8	11/16"	1.67'	14'	.0607	0.8484	Bottom flange
Trs. gd.	8	1 1/2"	1.67'	14'	.0975	1.3650	Bottom flange
Trs. gd.	8	2"	1.67'	14'	.1208	1.6912	Bottom flange
Trs. gd.	4	1 1/2"	1.67'	7'	.0975	0.6825	Bottom flange
Sol. pl.	4	2"	4.0'	16'	.1208	1.9328	Trans. girder
Mas. pl.	4	1"	4.0'	16'	.0688	1.1008	Trans. girder
L. cnt.	34	11/16"	1.5'	51'	.0607	3.0906	Top flange
L. cnt.	34	11/16"	1.5'	51'	.0607	3.0906	Bottom flange
L. cnt.	34	1 3/4"	1.5'	51'	.1208	6.1608	Bottom flange
L. cnt.	32	7/16"	5.5'	176'	.0389	6.8464	Web pl.
L. cnt.	2	7/16"	5.84'	12'	.0389	.4668	Web pl.
Sus. sp.	32	5/8"	1.50'	48'	.0506	2.4288	Top flange
Sus. sp.	4	1"	1.5'	6'	.0688	0.4128	Top and tottom fls.
Sus. sp.	32	5/8"	1.5'	48'	.0506	2.4288	Bottom at ends
Sus. sp.	16	1 1/4"	1.5'	24'	.0867	2.0808	Bottom at center
Pin. pl.	136	1/2"	12.67'	1,724'	.0489	84.3036	Sus. and cant. ends
Links	68	1"	2.67'	182'	.0688	12.5216	Sus. and cant. ends
"Zs"	1,056	3/8"	1.0'	1,056'	.0373	39.3888	Diaphragms
"Xs"	128	3/8"	.75'	96'	.0373	3.5808	Lateral brac.
Stiffs.	714	5/8"	.67'	479'	.0506	24.2374	5/8" all spans
Stiffs.	714	3/4"	.67'	479'	.0628	30.0812	3/4" all spans
Anchor	34	1/2"	1.33'	46'	.0489	2.2495	Top fl. cov.
Anchor	34	1/2"	1.33'	46'	.0489	2.2495	Bottom fl. cov.
End Ls.	64	3/8"	.75'	48'	.0373	1.7904	Conc. diaph. support
Exp. jts.	2	1"	240'	480'	.0688	33.0240	Tooth pls. curve cut
Exp. jts.	4	1"	1.0'	4'	.0688	.2752	Tooth pls. at ends
Exp. jts.	4	1"	1.0'	4'	.0688	.2752	Tooth pls. conn. pls.
Total of above						$372.316	

The writer has compiled the cutting costs from data obtained from the Lincoln "Procedure Handbook", A.W.S. literature and from practical welding and cutting mechanics and has taken the average costs so obtained.

However, on the admonition of one well qualified to advise, the suggestion that the above costs are too low and should be increased by about one-third, has been gratefully received and incorporated herein.

. Increasing the total by this amount and rounding out to the nearest even figure gives a working amount of $500.

While this figure still seems low, it must be borne in mind that this is the actual cost of cutting, handling is accounted for separately.

Arc Welding Costs—In determining these data, about the same general procedure has been followed as in analyzing the flame cutting costs, that is, basic information was obtained from any literature available, and also from practical operators of sufficient experience to render intelligent advice. From the general cross section so derived the costs and conclusions were decided.

In calculating the costs, it must again be borne in mind that only actual items of power and labor used in the welding operation, with the idle time and insurance overhead added, are shown in this tabulation. The cost of weld metal and that of placing, turning, etc. (manipulation) are listed elsewhere.

While some structural shops do not figure the electrical energy directly in estimating their costs, usually assuming it as general overhead, the cost is present and must be accounted for somewhere.

The tables giving the itemized breakdown of welding costs are founded on the following basic rates and factors:

Labor, including idle time and ins................$2.06 per hour
Power .... .02 per k. w. h.
Operating factors .... .50 & .60
Welding speeds, as indicated.
All operating speeds, voltages and amperages were taken from the "Procedure Handbook" and verified from field information.
The general formula for power cost is,

$$\text{Cents per foot} = \frac{\text{volts} \times \text{amperes} \times \text{rate/k.w.h.} \times \text{operating factor}}{1000 \times \text{welding speed} \times \text{operating factor}}$$

For butt welds the required power per foot is:

$$3/8'' = \frac{(25 \times 130) \times 2 \times 2 \times .5}{1000 \times 9.5 \times .6} = \frac{6{,}500}{5{,}700} = \$0.0114$$

$$7/16'' = \frac{(25 \times 130) \times 2 \times 2 \times .5}{1000 \times 7.5 \times .6} = \frac{6{,}500}{4{,}500} = 0.0144$$

$$1/2'' = \frac{(25 \times 130) \times 2 \times 2 \times .5}{1000 \times 5.0 \times .6} = \frac{6{,}500}{3{,}000} = 0.0216$$
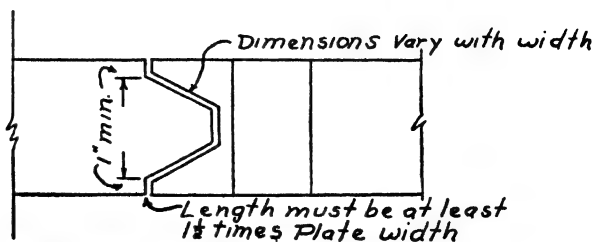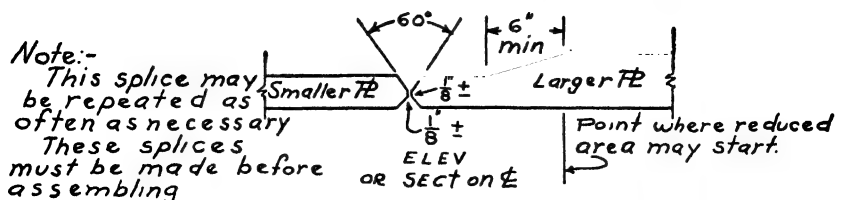
Fig. 5. Details of typical splice for tension flange plate.

$$\tfrac{5}{8}'' = \frac{(25 \times 150) \times 3 \times 2 \times .5}{1000 \times 3.8 \times .6} = \frac{11,250}{2,280} = \$0.0593$$

For fillet welds using 30 volts, 190 amperes, $0.02 rate, operating factors of .5 and .6, the cost depends on the speed and is:

$$\frac{30 \times 190 \times 2 \times .5}{1000 \times S \times .6} = \frac{5700}{600 \times S} = \frac{\$0.095}{S}$$

Size	"S"	Cost per Foot
¼"	35	$0.0027
5/16"	30	0.0032
⅜"	20	0.0048
7/16"	16	0.0059
½"	10	0.0096

As before stated, field welds are based on the time consumed, as all electrodes, of specified sizes, machine, operator and all other incidental expense is concluded in the price of $36.00 per day of eight hours or $4.50 per hour.

As all was ready for the welding operator and his idle time for rest and change of position was so reduced, the factor for that item will be taken at 20 per cent.

These costs will be computed as follows:

Overhead fillets, 5/16"............Speed 10 feet per hour
Overhead fillets, ⅜"...........Speed 7.5 feet per hour
Vertical fillets, 5/16"..............Speed 12.0 feet per hour
Vertical fillets, ⅜"..............Speed 12.0 feet per hour (using ¼" electrode)
Horizontal fillets, ⅜".... ....Speed 25.0 feet per hour

$$\text{Overhead } \tfrac{5}{16}'' = \frac{4.5}{10} \times 1.2 = \$0.54 \text{ per foot}$$

$$\text{Overhead } \tfrac{3}{8}'' = \frac{4.5}{7.5} \times 1.2 = 0.72 \text{ per foot}$$

$$\text{Vertical } \tfrac{5}{16}'' \text{ and } \tfrac{3}{8}'' = \frac{4.5}{12} \times 1.2 = 0.45 \text{ per foot}$$

$$\text{Horizontal } \tfrac{5}{16}'' \text{ and } \tfrac{3}{8}'' = \frac{4.5}{25} \times 1.2 = 0.26 \text{ per foot}$$

Shop Welding Labor Costs

Size	Horizontal		Vertical		Overhead		Single V Butt		Double V Butt	
	Speed Ft. per Hr.	Cost	Speed Ft. per Hr.	Cost	Speed Ft. per Hr.	Cost	Speed Ft. per Hr.	Cost	Speed Ft. per Hr.	Cost
¼"	35	$0.0588	18	$0.1140	13	$0.1584	15	$0.1373	....	....
5/16"	30	.0686	13	.1584	11	.1872	12	.1716	....	....
⅜"	20	.1030	9	.2288	9	.2288	9	.2288	....	....
7/16"	16	.1287	6	.3430	7.5	.2746	7.5	.2746	....	....
½"	10	.2060	5	.4120	5.5	.3745	.5	.2060	....	....
⅝"	6	.3433	4	.5150	....	....	....	....	8	$0.2575
11/16"	6	.3433	4	.5150	....	....	....	....	8	.2575
¾"	4	.5150	3	.6860	....	....	....	....	....	....
1"	2	1.030	1.5	1.3730	....	....	....	....	....	....

Description	Size	Class	Power per Foot	Labor per Foot	Total Length	Total Cost
Sus. sp. stiffs.	5/16"	Vert.	.0032	.1584	10,461	$1,690.50
Anch. sp. stiffs.	5/16"	Vert.	.0032	.1584	13,486	2,171.34
Lon. cant. stiffs.	5/16"	Vert.	.0032	.1584	2,651	428.40
"Z" diaph.	5/16"	H. & V.	*	.45	3,520	1,584.00
Ls end diaph.	5/16"	Hor.	.005	.1650	256	43.52
Trans. gird. dia.	3/8"	Vert.	.005	.2288	920	215.10
Comp. struts.	5/16"	H. & V.	.0032	.1659	658	111.27
Gird. seats.	5/16"	H. & V.	.0032	.1659	276	46.67
Trans. gdr. sol. pl.	1/2"	Hor.	.0096	.2060	64	13.80
Bottom laterals.	5/16"	....	*	.54	512	276.48
Pin plates.	1/4"	Hor.	.0027	.0588	1,724	106.03

Flange to Web

Description	Size	Class	Power per Foot	Labor per Foot	Total Length	Total Cost
Sus. sp. T. and B.	5/16"	Hor.	.0032	.0686	6,108	$ 438.55
Sus. sp. Bottom.	3/8"	Hor.	.0048	.1030	2,034	219.26
Trans. grd. cen.	1/2"	Hor.	.0096	.2060	960	206.97
Trans. grd. outsd.	5/16"	Hor.	.0032	.0686	640	45.95
Anch. sp. top.	3/8"	Hor.	.0048	.1030	5,321	573.60
Anch. sp. bottom.	3/8"	Hor.	.0048	.1030	5,406	582.77
Long. cant. T. and B.	3/8"	Hor.	.0048	.1030	3,780	407.48
Anch. and cant. to tr.	5/16"	Vert.	*	.45	44	19.80
Anch. and cant. to tr.	5/16"	Vert.	*	.45	684	307.80
Bottom fl. to seats.	5/16"	....	*	.54	68	36.72
Sus. sp. butt and fl.	5/8"	D. "V." B.	.0593	.2575	77	24.39
Sus. sp. butt and T.	5/8"	D. "V." B.	.0593	.2575	51	16.16
Sus. sp. webs.	7/16"	S. "V." B.	.0144	.2000	92	19.73
Anch. webs, B't.	3/8"	S. "V." B.	.0114	.1850	148	29.07
Anch. bottom fl.	5/8"	D. "V." B.	.0593	.2575	51	16.16
Anch. bottom cov. pl.	1/2"	S. "V." B.	.0216	.2060	46	10.47
Anch. bottom fl. cov.	5/16"	Hor. Fill.	.0032	.0686	2,057	147.69
Anch. top cov. pl.	5/16"	Hor. Fill.	.0032	.0686	2,193	157.46
Anch. and cant. ov. trans.	3/8"	Hor. Fill.	*	.260	1,349	350.74
Ornament supports.	1/4"	Vert.	.0027	.1140	144	16.80
Sole pls. to anch.	3/8"	Hor.	.0048	.1030	136	14.66
Ornament pls., ends.	1/4"	Vert.	.0027	.1140	48	5.60

Total Welding Cost, Power and Labor $10,334.94

*This symbol denotes a field weld, the cost of which is previously explained in foregoing text.

The following data are submitted in support of the breakdown of estimate which will be further analyzed and tabulated.

Steel at Mill—This price taken from "Engineering News-Record."

Electrodes—Cost of this material given by proprietor of a commercial welding shop.

Labor—Rate given by employees of a large structural shop.

Insurance and **Idle Time Assumptions**—Same source as above.

Freight—Rate obtained from agent of N. Y., N. H. & H. R. R.

Loading and **Unloading**—Estimated from observations of writer. Not verified but cost stated as reasonable by an old structural steel superintendent.

Manipulation—From same source as above. Includes boring, turning pins, threading same, all milling of comp. struts, stiffeners, diaphragms and all other machine work.

Erection—Also from same source as above.

Haul—Price obtained from manager of local trucking and rigging firm. (Given as "about", not exact.)

Center Support—Price obtained from general contractor (the builder).

Paint—Amount of paint from Ketchum's "Design of Highway Bridges", Ed. 1908. Cost of paint and application from data compiled by Bridge Sup't State Highway Dep't.

Other items are explained and analyzed in the foregoing.

Additional Cost Data—Freight, Pittsburgh to Trenton (mill to fabrication shop, 352 miles, $0.24 per cwt.).

Manipulation, for cutting, $0.005, total.

Manipulation, for welding, also all machine work, $0.01, total.

Loading, mill and shop after fabrication, to trucks on arrival at siding, unloading at fabrication shop and at site and siding, $1.00, total for all.

Freight, Trenton to Hartford, 170 miles, $0.24 per cwt.

Haul, 1 mile at $0.40 per ton mile.

Paint, 1st coat, shop, $\frac{1}{2}$ gallon per ton, 2nd and 3rd coats, $\frac{3}{8}$ gallon per ton each. Total, $\frac{1}{2} + \frac{3}{8} + \frac{3}{8} = 1.25$ gallons per ton. Cost of paint + application = $5.00. Amount, 850 tons at 1.25 gallons per ton = 1,062.5 gallons. Use 1,100.

The following resumé gives the costs on which the steel contractor could base his bid.

1,700,000 lbs. structural steel at $0.021	$ 35,700.00
Freight, mill to shop	4,080.00
Freight, shop to siding	8,450.00
Loading and unloading, all operations, at $1.00 each per ton	850.00
Haul, siding to site, 850 tons at $0.40	340.00
Manipulation, all at $0.015	2,550.00
Flame cutting	500.00
All arc welding	10,361.00
Shielded Arc Electrodes, 21,200 lbs. at $0.08	1,696.00
Erection, 850 tons at $20.00	17,000.00
Center support*	1,500.00
Paint, 1,100 gals. at $5.00 applied	5,500.00
Total of above	$ 88,527.00
Profit, 15% of above total	$ 13,279.05
Estimated cost of structural steel in place	$101,806.05

Dividing the above total by the weight, 1,700,000 lbs., gives a unit price of $0.05988. Contractors bid was $0.075.

*Center support is for suspended span until concrete hardens (21 days).

In quoting a price of $0.075 per pound for the structural steel in place, reference is made to the bid of the general contractor. What the steel fabricator may have bid to the general contractor is not known to the writer, but it is customary practice for the latter to offer the same unit price on structural steel as is quoted to him.

Strangely enough the bid on most of the principal items of this contract were identical with the unit prices of the preliminary estimate. Although great care was exercised in the preparation of the latter, it is seldom that an estimate runs as close to the bid prices as in this case.

In order to estimate the amount of steel, incidentally money saved by the use of welding in place of riveted construction, a design and estimate of a riveted plate girder substituting the welded suspended span girders and using the conventional type of construction. The slab will not be combined with the girder as in the case of the one constructed and no composite action is possible.

The span will be the same and the depth of the girder must remain as before.

Dead loads, Slab, .58 × 5 × 150 = ... 438 lbs. per ft.
Future Pav't @ 25 lbs. per sq. ft. 5 × 25 .... 125 lbs. per ft.
Girder, est. @ .... 400 lbs. per ft.
Misc. details .... 37 lbs. per ft.

Total lbs. per ft. .... 1,000 lbs. per ft.

Dead Load Moment,
$1{,}000 \times 120^2 \times 1.5 =$ .... 21,600,000 in.-lbs.

Live Load Moment, "H-20"
$640 \times \frac{5}{9} = 356$ lbs. per lin. ft. Uniform Load.
$18{,}000 \times \frac{5}{9} = 10{,}000$ lbs. Concentration.

Impact, $\frac{50}{L + 125} = 20.4\%$ use 21%

Live Load Moment, Unif. $356 \times 120^2 \times 1.5 =$ .... 9,304,416 in.-lbs.
Live Load Moment, Conc. $10{,}000 \times 120 \times 3 =$ .... 4,356,000 in.-lbs.
(21% Impact included in above)
Total including Dead Load Moment .... 35,260,416 in.-lbs.

For Web, Max, End Shear, Dead, Live and Impact .... 103,323 lbs.

Web Area Required $\frac{103{,}323}{11{,}000} = 9.4$ sq. ins.

$t = \frac{9.4}{64} = .147$ ins.

By Specs. $= \frac{1}{170}$ clear dist. or $\frac{64-12}{170} = .305$—use $\frac{3}{8}''$

Area Web, $64 \times .375$ 24 sq. ins. $\frac{1}{8} =$ .... 3 sq. ins.

Required Flange Area $\frac{35{,}260{,}416}{63 \times 18{,}000} =$ .... 31.1 sq. ins.

Less $\frac{1}{8}$ Web .... 3.0 sq. ins.

Net Flange Area Required .... 28.1 sq. ins.
$\frac{1}{2}$ area in angles, 2 Ls $8'' \times 6'' \times \frac{5}{8}''$ .... 14.22 sq. ins.
Required area plates .... 13.88 sq. ins.
1 sq. in. out, 18″ plate 16 t = 13.88, t = .8675, use $\frac{7}{8}''$
Weight per ft. at center, Web .... 81.6 lbs. per ft.
4 Ls $8'' \times 6'' \times \frac{5}{8}''$ .... 114.0 lbs. per ft.
2 pls. $18'' \times \frac{7}{8}''$ .... 107.1 lbs. per ft.

Total .... 302.7 lbs. per ft.

Moments at Quarter Point

D. L. M. $60{,}000 \times 30 - (30 \times 1{,}000 \times 15) \times 12$ .... 16,200,000 in.-lbs.
L. L. M. (unif.) $356 \times 60 \times 30 - (30 \times 356 \times 15) \times 12$ 5,767,200 in.-lbs.
L. L. M. (conc.) $\frac{10{,}000 \times 90}{120} \times 30 \times 12$ .... 2,700,000 in.-lbs.
Impact 21% .... 1,778,112 in.-lbs.

Total .... 26,445,312 in.-lbs.

Flange Area Required $\frac{26,445,312}{61.46 \times 18,000}$ = ... 23.9 sq. ins.
1/8 Web .... 3.00 sq. ins.
2 Ls 8″ × 6″ × 5/8″ .... 14.22 sq. ins.
Plate Area Required .... 6.68 sq. ins.
16 t = 6.68   t = .417″ use 1/2″
Instead of a 7/8″ plate at the center the area should be made up, of one 1/2″ plate full length and one 3/8″ plate ending near the quarter point.
Stiffeners, 6″ × 4″ × 3/8″ × 63 1/4″ long.
Weight, 12.3 × 5.27 .... 64.82 lbs.
Fillets 3 1/2″ × 5/8″ × 51″ long.
Weight 7.4 × 4.25 .... 31.45 lbs.

Total .... 96.27 lbs.
52 stiffener assemblies per girder, weight 52 × 96.27 .... 5,006 lbs.
4 one half length 4 × 48.13 .... 192 lbs.

Total all stiffeners .... 5,198 lbs.

Weight of Girder Complete

Top angles, 117.84 × 28.5 × 2 .... 6,716.88 lbs.
Bottom angles 122 × 28.5 × 2 .... 6,954.00 lbs.
Web, 64″ × 3/8″   81.6 × 120 .... 9,792.00 lbs.
Splice plates (assumed) 52″ × 48″ × 3/8″ (web)
Weight 19.5 ×4 × 2 .... 156.00 lbs.
Flange splice (also assumed) .... 684.00 lbs.
Gussets for Zs, 12″ × 1′ 6″ × 3/8″
Weight 15.3 × 1.5 × 16 .... 367.20 lbs.
Z braces angles 6″ × 4″ × 3/8″, length all, 14′ 6″
Weight 14.5 × 12.3 × 8 .... 1,426.80 lbs.
Pin. plates $\frac{1.5 + 2.5}{2}$ =1.75 × 4 × 15.3 .... 214.20 lbs.
Top cover plate 18″ × 1/2 × 117.8 .... 3,604.68 lbs.
Top cover plate 18″ × 3/8″ × 60′ .... 1,377.00 lbs.
Bottom cover plate 18″ × 1/2″ × 122′ .... 3,733.20 lbs.
Bottom cover plate 18″ × 3/8″ × 60′ .... 1,836.00 lbs.
2-splice plates 18″ × 1/2″ × 6′ 0″ × 2 .... 367.20 lbs.

Sub-total .... 42,427.16 lbs.
Rivet Heads, 7/8″ diameter
Short stiffs. 5 × 4 × 2 40
Standard stiffs. 9 × 26 × 2 468
Flanges 8 per ft. 8 × (117 + 120) × 2 3,792
Z's 9 × 16 × 2 288
Web splices 80 × 2 160
Pin plates (est.) 52

Total rivet heads 4,800
Hanger links 124.25 × 4 .... 497 lbs.
4,800 rivet heads 24 lbs. per 100 .... 1,152 lbs.
Total weight of all steel per girder .... 44,246 lbs.
.4% allowed for paint .... 176 lbs.
Total pay weight .... 44,246 lbs.

According to previously given figures the welded girder weighs, 33,620 pounds net or 33,755 pounds with the paint allowance.

From these figures it is readily seen that the riveted girder is about 31 per cent heavier than the welded type.

It is reasonable to assume that the same percentage of increase will be carried throughout the entire structure.

The total weight of a riveted girder bridge according to this assumption would be 1,700,000 × 1.3 = 2,210,000 pounds.

The lowest price received for riveted girder work within the last year is $0.06, while the average was $0.0625.

Cost of welded type, complete structure..$127,500.00
Cost of riveted type, complete structure 2,210,000 × 0.06.......... 132,600.00
Difference in favor of welded bridge.. 5,100.00

Part of the saving, however, is offset by the cost of the stirrups used in the composite center span girders. This steel weighs about 12,000 pounds but the contractor bid the same amount for these as for the rest of the reinforcement, $0.04, which included the welding in place. This welding is not considered in this paper.

Other welding done on this structure included that on the ornamental handrail, but it is difficult for anyone not intimately associated with this specialized business to make an intelligent analysis of this type of railing.

On completion, this bridge is to be painted a dark tan, with a darker shade for the railing. The piers and abutments are faced with artificial or "cast" stone, colored to simulate Portland sandstone.

The contract for this project was awarded in early May, 1941. The substructure was completed in late November of that year. The structural steel began to arrive in March, 1942 and all erection and structural welding was completed about May 15, 1942.

It is expected that this bridge will be completed on or about July 1st, and the entire by-pass, including the main bridge over the Connecticut River will be completed and opened to traffic by September 15, 1942.

When this is accomplished another important link in the Boston to New York traffic chain will be in service and it is hoped that another important traffic congestion problem will have been solved.

In the itemized breakdown of the welding costs it may be here stated that the various items were not "jockeyed" to arrive at the same figure as that bid by the contractor.

When the estimate for the allocation of money for the project was prepared, the figure of $0.075 was used and based on bids received on smaller welded structures recently designed.

Many of the items entering into the total cost of the structural steel seem, even to the writer, to be somewhat inconsistent, that is, some too high, some too low.

As an instance the total cost of all cutting at $500 appears to be too low, yet a fair labor rate was used, a conservative conception of the speed curves and gas costs was also used.

On the high side, the erection unit price of $0.01 would seem to be excessive, but that price was obtained from a reliable and authoritative source. It may well be assumed that although some items may be high and some low, there appears to be a balance in general and the final amount is practically what it should be.

It may be of interest to give a complete list of all the contract items and the unit prices as bid by the contractor, so this shall follow.

Items	Unit	Quantity	Unit Price	Total
Clearing and Grubbing	L.S.			$500.00
Bridge Excavation*	C.Y.	4,400	$1.50	6,600.00
Stone for Drains*	Tons	70	2.00	140.00
½" Expansion Joint	S.F.	830	0.50	415.00
Deformed Steel Bars	Lbs.	438,560	0.04	17,542.40
Structural Steel*	Lbs.	1,700,000	0.075	127,500.00
Metal Bridge Railing	L.F.	800	12.00	9,600.00
Class "A" Concrete*	C.Y.	4,280	14.00	59,920.00
Cast Stone	L.S.			15,000.00
Cast Stone Ornaments	Each	4	50.00	200.00
Cast Iron Ornaments	L.S.			2,500.00
Copper Flashing	Lbs.	710	1.00	710.00
Portland Cement	Bbls.	6,225	2.40	19,940.00
Total Bid for Contract Items				$260,567.40
State's Estimate for above items				256,699.50

Items marked thus * were bid by contractor at same unit price as was estimated by the State.

Summary and Appendix—This section of the paper has been prepared with the thought of endeavoring to clarify, explain, excuse, reason, or, perhaps, alibi some of the data and other matters appearing from time to time.

The design of this bridge was started in the Fall of 1940, when, although war clouds may have been dimly visible on the horizon, at least there was no scarcity of any commodities, steel in particular. Were conditions at that time as they are at present (May 1942) this project would have been indefinitely postponed along with all of its steel companions and perhaps those of reinforced concrete on this by-pass.

This paper is written in the vein of peace time design, with all materials readily available and labor in its normal state. Such conditions must again prevail before the project can be duplicated.

However, some changes were made, differing from the original design, just because of these abnormal conditions, and they have, for the most part, been taken into account as far as they are known to the writer. This is responsible for the change in tense, from "is" to "was" and vice-versa in many places during the discussion. Minor shop changes which would not be incorporated in another similar design but were made because of the lack of some particular size of material, will not be mentioned, although there were several such substitutions.

The writer has always been firmly of the opinion that welding could best be promoted by proof of its economical use, but if some of the fillet sizes and other items of welding called for seem to be, (and are) of excessive size, it is because of the fact that this bridge was designed under specifications which are unreasonably conservative, a condition that the writer is confident will soon be corrected.

In treating the design of the suspended span girders, it may have been noted that the size of the reinforcing steel for the stirrups was not stated but assumed. The size is not known to the writer even at this time, but this particular type of design is adaptable to any size reinforcement. While the size bars in the foregoing was assumed at ½ inch square the spacing and other details were not worked out for reasons as stated.

With reference to this type of design, the writer does not claim this to be his original development. Whoever developed the "Tee" beam theory belongs the credit of this design as there is little, if any, difference. As long
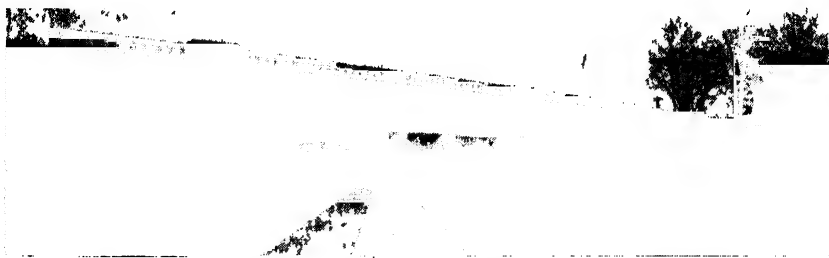
Fig. 7. Structure completed.

ago as 1925 the writer endeavored to develop a design similar to this one, applying the same theory to the use of "I" beams but while the paper design was "successful," lack of welding knowledge prevented the project from becoming a tangible object.

The reason for a considerable understress in the tension flange of the suspended span girders was because of the fabricator's objection to a 12" x ½" top flange plate, adequate for stress requirements but too flexible for erection because of the length.

It may appear that too much time and effort have been spent on the details of design. The reason that this has been done is because many engineers as well as students have asked the writer so many different questions and have shown such a genuine interest in the project as a whole, that he believes a complete structural design may well accompany the welding treatise. The design is, however, nothing greatly out of the ordinary.

One question which has been propounded is relative to the depth of the center span girders. Several seem to believe that a saving of metal would have been possible by increasing the depth of these girders. This is true, but certain under clearances had to be maintained and every foot the grade was raised added terrifically to the cost. There are side slopes of 1:2, which means that for every foot of height the width increases four feet, and as acquisition of real estate was both difficult and expensive, each four feet saved effected an appreciable saving in dollars.

Another reason for the relatively shallow center girders is that it was highly desirable that the grade be kept as low as possible in order to require as little borrow as necessary. There was little filling material in the vicinity of this bridge, the haul was long and consequently expensive.

One other point regarding the excess of welding used in several connections. The writer, on request from the fabricator, agreed to the use of intermittent welding on the top cover plates over the transverse girders on finding from a review of the design that this was possible. This was also done at the extension cover plate on the top flange of the anchor span girders where there occurs a reversal of stress, but the fillets are more than adequate. An adjustment in price was also effected. As this was not figured in the original design, it therefore was not considered in the cost analysis.

In choosing a title for this paper, the writer does not seem to have selected one which sounds in the least impressive. There are many welded plate girders in existence, large, small, light, heavy, handsome and some are extremely hideous, the latter seeming to predominate.

The writer believes that this bridge will present a picture quite the opposite to the last named adjective, partly through his own efforts and mostly from the artistic touches of a skillful architect, who, by the simple addition of a few cast iron ornaments on the outer girders, the design of a handrailing embodying several silhouettes, symbolical of industry and history (Aeroplane production, Charter Oak, etc.) has transformed what might have been questionable to pleasing in appearance.

What once was a wide and spacious intersection now seems dwarfed and subordinated to the structure which accommodates four lanes of high speed traffic, yet on the lower level traffic is no more constricted than it was previously.

While this bridge now occupies practically all of what was once known as "Goodrich Square" there seems to be but little local opposition to the structure, contrary to what was expected. This bridge is promoted as a welded project for reasons which will be subsequently given.

As far as the writer has been able to determine, it is the largest purely highway grade separation in New England, not only based on its total span or its width but on the quantities of material, the width of area of the intersecting streets on the lower level and the money involved.

There are 1,700,000 pounds of carbon structural steel in its makeup. There are about 12 tons of welding rods or electrodes. The total length of all the fillet welds is something over 12 miles.

When measured against the enormous structures of modern times, this structure may not seem, and is not really large. But when compared to the many bridges of its own class it will become outstanding.

The division of the public which will benefit the most from this structure is the motor car driver, him whose money has made this and practically every other major highway project possible.

Every grade separation is one less driving hazard. When grades must intersect on the same level as in this case, (Jordan Lane and Franklin Avenue) the wider the intersection is made the safer is the intersection itself.

In all probability, right turn connections will be built under the anchor spans in the near future. While it is not claimed that the bridge is responsible for this improvement, it is evident that the bridge will in no way act adversely.

In conclusion, the writer believes that the bridge described herein fulfills the requirements of the traffic problem as hereinbefore stated.

There is little doubt that the smooth, clean and regular appearance created by welding will appeal to the layman as well as the engineer. That fact is now well established.

Again viewing the project as one designed and built in normal times, it may be safely stated that the steel industry reaps an appreciable harvest in the sale, fabrication and erection of 850 tons of their product; manufacturers of shielded electrode benefit to the extent of 12 tons of their product, railroads, truckers and commercial welderies also enter the picture as cobeneficiaries.

With reference to commercial welderies, it is highly encouraging to the structural engineer who plans to depend heavily in the future on welding as a means of assembly, to note the remarkable service that these companies are now capable of rendering. This fact alone will remove one large uncertainty from the minds of structural engineers who have been heretofore somewhat hesitant about specifying welding.

Like any steel bridge, if the color scheme is not satisfactory or have the appearance anticipated, a change may be easily effected.

Finally, in designing and promoting a welded girder grade separation of the magnitude of this, the writer hopes that it will help to abolish the reluctance toward welding on a large scale and that the true value and economy of arc welding may be appreciated.

This bridge is on the main artery leading from the giant Pratt and Whitney Aircraft factory, so, with no credit to the writer, probably there is one who will benefit most, that grand old gentleman who we all criticize yet love, Uncle Sam.

Chapter V—Trusses for Swing Bridge

By B. M. Shimkin,

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B. M. Shimkin

Subject Matter: Detailed comparative designs for a semi-welded and for a full-welded highway swing bridge of 287-foot span. The semi-welded has just been opened for traffic (June 1, 1942). The full-welded span is to be built this year (1942). A similar all-riveted span was built in 1936.

The use of arc welding started actually in the time of the first great war as a faster and more flexible type of structural connection than riveting.

In the infancy of welding it was used in case of emergency only, and as soon as an emergency was over the old riveting method came back in full might, especially in countries where an enormous sum of money was invested in manufacturing and riveting machinery.

In the same time the designing engineers restrained themselves from using welding in their practices, being not so familiar with this new type of connections and not so sure about allowable stresses and a control of technique of welding.

But arc welding had and has its own pioneers, who always saw the greatest possibilities of welding in steel construction and with inexhaustible energy worked in this line.

The best pioneer forces organized the American Welding Society and approached the welding on experimental and scientific bases and at the present time this society is rightfully considered as the expert and authority on welding. Its specifications are used as standard by most engineering organizations, not only in the United States of America but throughout the whole world.

But this society could never reach such results without the help and support from the American electrical and welding manufacturers. By their mutual effort and work now the arc welding is officially accepted in construction and design of steel structures and a course of welding design is included in a curriculum of engineering colleges.

Recently graduated young engineers now have the knowledge of welding design and its application from the colleges and they are not afraid to use that in their practices. All new structural handbooks and textbooks have data and details of arc welded connections as well as riveted ones.

The second great war found arc welding in its maturity and was used from the beginning on a great scale, especially in shipbuilding.

On February 16th of this year (1942) the Secretary of the Navy, Frank Knox, on the launching of the 35,000-ton battleship "Alabama," said that the

use of welding and other means in the $80,000,000 Alabama have so decreased its structural weight as to add considerably to its capacity for guns, armor and ammunition. And everybody understands what that means in war time.

At the present time, arc welding has passed a period of pioneer experimental stage and entered into a stage of scientific and manufacturing perfection.

With unlimited American science and ingenuity, arc welding will be soon perfected and become the one and only type of structural connections and will replace the old, out of date riveting.

Steel structures replaced iron; electric power replaced steam; now in the age of electricity—electrical arc welding will replace mechanical riveting.

It is an evolution and cannot be another way.

This paper presents the design for a highway two-lane swing bridge truss. Both riveted (semi-welded) and welded trusses are presented, together with an economic comparison of these two types.

General Discussion of Project—This swing bridge (riveted and semi-welded) was designed and built in the United States of America during 1941-42 and will be open to traffic on June 1, this year, (1942).

The duplicate swing bridge is expected to be built during this year at another site. The similar, the same span all-riveted swing bridge was built in 1936 (for H-15).

In the construction of the present, (See Fig. 1), swing bridge (for H-20-12)
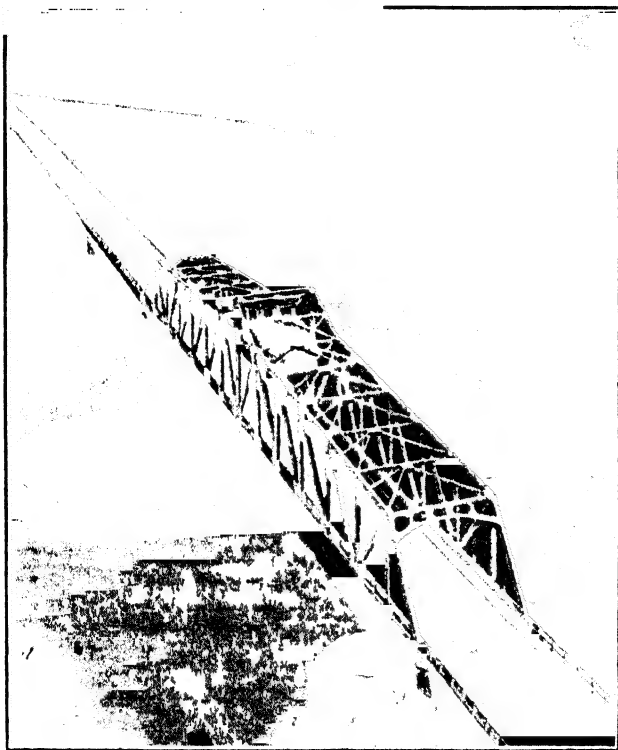
Fig. 1. The arc welded swing bridge.

arc welding was permissible to use in limits, prescribed by the American Association of State Highway Officials Specifications 1938.

The total amount of arc welding used in the present structure equals to 2032 feet (mostly $\frac{5}{16}$ inches) or 483 pounds of electrodes.

The soil conditions at the site are such that the height of the road fill is limited and total length of structure was fixed as well as the grade of bridge deck. This bridge crosses a navigable river and must be open for passing ships.

With such a *limitation* the comparative estimates of swing and bascule bridges, (See Tables I and II), were prepared and show a saving in favor of swing bridges—4.8 percent.

Also, according to Otis Ellis Hovey, Assistant Chief Engineer of the American Bridge Co.—"A swing bridge is the simplest, best and most economical type in first cost and maintenance." Farther on he said:

"An engineer, when discussing with another the question of the selection of the most suitable type, expressed his views quite simply. His first choice was a bridge that remained on the ground when open; his second was one that had only one end lifted in the air; and his third, one in which both ends were lifted. This is, first, swing; second, bascule; third, vertical lift. . . . In addition to economy in foundations masonry, and weight of superstructure, another important saving of the swing bridge is the reduced cost of the steelwork and erection." (Movable Bridges, by Hovey, Vol. I, pp. 20-22-27).

The cost of maintenance for swing bridges is less than for bascule bridges.

The Annual Reports of the Department of Bridges, City of New York (for period 1913-1916), based on data for six swing bridges and ten bascule bridges of the same spans, shows the cost of maintenance and operation.

Bascule bridge for year	$9467
Swing bridge for year	7916

Our State (period 1939-1941) based on data for three bascule and three swing bridges

Bascule bridge for year	$9740
Swing bridge for year	4298

These comparative figures can be accepted in a broad statement only, for there are too many factors involved to make an accurate comparison possible.

However, the study of maintenance expenses revealed that the greatest part of the money goes to repair and replacement of deck on bascule bridges. By the nature of the bascule bridge it requires lighter deck slab —to reduce counter balance, footing and weight of truss, but at the same time a constantly increasing speed and weight of traffic vehicles demanded a good solid deck slab, which can be furnished by a swing bridge only.

Description Project—The swing bridge, described in this paper, was built in a lowland country, where the soil has very poor bearing capacity and an unlimited space for such a kind of bridge was provided. The roadway width of bridge is 26-feet–0-inches between curbs and two sidewalks of two feet wide were built. The modified Pratt trusses were used with 31-feet–9-inches between centers of trusses, and 287-feet–3½-inches between abutment bearings. The center bearing was based on center round reinforced concrete hollow pier 40-feet–6⅞-inches diameter with 143 Douglas fir piles.

The center pier and abutments are protected by the fenders. For navigation two 110-foot clearances are provided.

TABLE I—Estimate of Bascule Bridge (146-foot)

110 Foot Clearance
26 Foot Roadway + 2@ 2 Foot Sidewalks

1.	Structural steel—710,000 @9c	$ 63,900.00
2.	Machinery—80,000 @50c	40,000.00
3.	Floor and handrail	3,280.00
4.	Counterweight:	
	Concrete 401c.y @18.00	7,210.00
	Reinf. steel 9100# @5c	460.00
5.	Operator's house and electric equipment	15,000.00
		$129,850.00
	Royalty 5%	6,490.00
		$136,340.00
7.	Two fenders	2,540.00
8.	Pier	40,500.00
		$179,380.00
	To span difference (287'-3½") — 146' = 141'-3½", use additional concrete spans 50'-41.29'-50'.	
9.	Structural steel—132,000 @9c	11,880.00
10.	Reinf. steel—22,500 @5c	1,125.00
11.	Concrete 113c.y @$20.00	2,260.00
12.	Concrete piles 21@(80') @$2.45	5,145.00
		$ 20,410.00
	From 1 to 12:	$199,790.00
	Contingencies 15%	29,970.00
		$229,760.00

TABLE II—Estimate of Swing Bridge (287-foot—3½ inches)

2@110 Foot = 220 Foot–0 Inches Clearance
26 Foot Roadway + 2@2 Foot Sidewalks

1.	Structural steel—759,000# @9c		$ 68,310.00
2.	Machinery—88,500# @50c		44,250.00
3.	Floor: Concrete—173c.y @18.00 Reinf. steel—47500# @5c Handrail—574' @1.50		6,350.00
4.	Fender and piles		1,270.00
5.	Operator's house, electric and gas equipment		23,000.00
6.	Draw rest:		
	Reinfor. steel—18,500# @5c	$ 925.00	
	Tremie concrete—370c.y @15.00	5,550.00	
	Struct. concrete—528c.y @20.00	10,560.00	30,212.00
	Gravel—143 @3.00	429.00	
	D. F. piles—143 @36.00 (60' long)	5,148.00	
	Struct. Excavation—950c.y @8.00	7,600.00	
7.	Fender round pier		
	D. F. 89 M.B.F. @ 90.00		8,010.00
	244—D. F. piles 65' @ 38.00		9,272.00
			$190,674.00
	Contingencies 15%		28,601.00
			$219,275.00

Note: The comparison of estimate of swing bridge and bascule bridge shows a saving in favor of swing bridge = 4.8%.
Unit prices based on the actual competitive bidding 1940, on which contract is given.

All machinery, abutments, piers and other details which are common for both (welded and semi-welded) designs are omitted from consideration in this paper. Only, it should be mentioned that the machinery weights expressed in percentages of structural steel weights for highway bridges equal to from 12 percent to 13 percent for span of 200-feet–300-feet. It was checked in our design and gives 11.7%, and is also given in Table 3L of "Movable Bridges" by O. E. Hovey (Vol. 1, p. 79). Such percent (12%) was used in final estimate for welded structure.

For better comparison of the two designs, the controlling dimensions and general features of the welded design were made the same as for the semi-welded one. An exception was made for the deck slab of welded design,—using "I-beam-lok armored bridge roadway slab", filled with Haydite concrete, instead of reinforced concrete slab used in present bridge.

It should be mentioned also that the design of swing bridge is quite different compared with a common truss bridge. It is not only a bridge, but
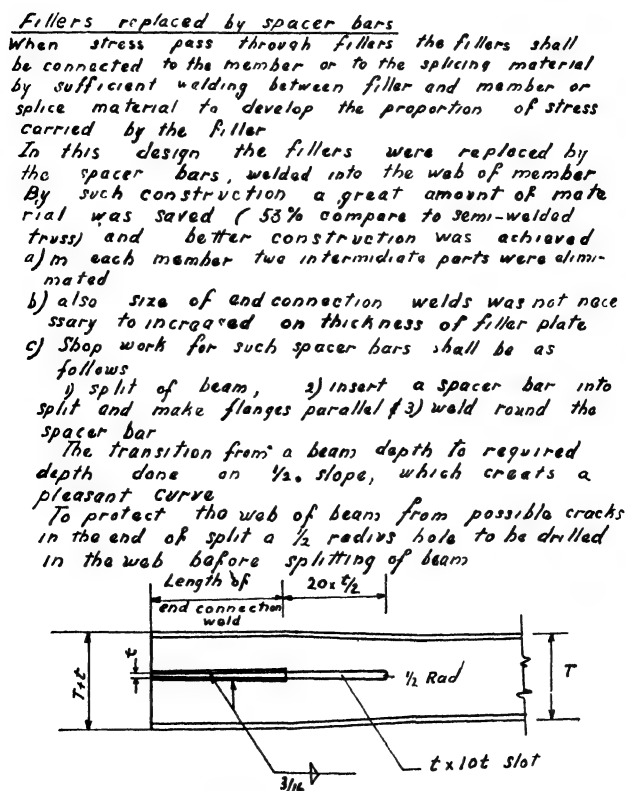
Fig. 2. Welded truss for swing bridge.

a bridge and a great deal of machinery and a special equipment (locks, buffers, gates, signals, operator's house, etc.).

To obtain the design stresses for members of truss it required calculation of stresses in five loading cases and later five combinations of such cases. After that many members should be checked to additional wind, bending and eccentrical loading stresses. These additional stresses considerably increase section areas of members compared with areas required by the "design stresses" only.

Construction—The presence of the rest draw and fenders in a swing bridge create the most ideal conditions for an erection of trusses.

The contractor has a platform to work on without any extra expense for false work, in contrary he is paid for that.

The welded members and fillets to gusset plates were shop fabricated and no field welds were used in construction of present bridge. However, electricity was available on the site from the beginning of work.

The absence of rivet heads on welded members gives a smooth nice appearance and creates a beautiful impression compared with riveted members and decreases painting expenses; also increases the life of bridge by elimination of many "starting points" of rusting around rivet heads.

In the case of full welded trusses the benefit of the rest draw will be extended by omitting the seat angles for the floor girders, stringers and other members and supporting of all these members directly from the unyielded platform for the field welds. That saves a great deal of construction expenses. Again, the rest draw gives to the welders and their equipments the best working conditions compared with any other construction on false work and will increase their efficiency.

No filler plates are used in new welded trusses. They are replaced by the spacer bars, described in details in Fig. 2, which gave simpler details and eliminate ambiguous design for filler plates.

The American Welding Society formulas for calculation of the required area of welds for end connections of the truss members give quite great areas for welds and, finally, such excess creates total amount of field welds greater than shop welds. (See Table III).

In the present case this disadvantage of field welds will not increase considerably the cost of construction, because 1) electricity available on the site; 2) presence of the rest draw gives the best conditions for work; 3) simplicity of erection; and, 4) local perfect climatical conditions—and all these factors will insure about the same surroundings as in the shop.

General procedure of construction for welded trusses will be practically the same as for riveted one—start from center pivot girder and proceed to ends—and to be executed according to the best present welding practice and the specifications of the American Welding Society and the American Association of State Highway Officials.

The observation of construction of the present semi-welded trusses for swing bridge and also many other jobs where welding is amply involved gives full confidence in the ability of the qualified welders, civil engineers and contractors to handle and accomplish such a job with the best results and economy.

Weight and Economical Comparison of the Two Types—The weight and economic superiority of the welded trusses is shown in Table IV and in the Estimate of Swing Bridge (welded trusses) in Table V.

Table III—Estimate of Shop and Field Welds, Used in Construction of Welded Trusses for Swing Bridge.

	3/16″		1/4″		5/16″		3/8″		1/2″		5/8″		Lbs. of Weld
	Shop	Field	Shop	Field	Shop	Field	Shop	Field	Shop	Field	Shop	Field	
Truss	1540	16	428		28	9	103	708	113	127		94	717
Top and bottom bracings	60	16	172	93		69	18	44		18			109
Floor		293		507	94			413					299
Portal and sway bracing	100	33	17	20	43	15	17	64					64
Pivot Grdr.			150		24		64	21	48	40			126
Ring Grdr.	112		242	42		12							83
Length	1812	358	1009	662	189	105	202	1250	161	185		94	
Unit weight	.10	.10	.20	.20	.25	.25	.35	.35	.55	.55		.80	
Weight	181.2	35.8	201.8	132.4	47.2	26.2	70.1	437.5	88.6	10.2		75.2	1398

From total amount of weld—Shop welds—589 lbs.—42%,
Field welds—809 lbs.—58%.

Note: As in specifications of present "semi-welded" trusses for swing bridge.—"Full compensation for all weld metal used in making shop or field weld, shall be considered as included in the prices per pound for furnishing and erecting the steel. All weld metal used in making welds will be paid for at the prices per pound for furnishing and erecting structural steel."

Table IV—Comparison of Weight of Riveted and Welded Design.
(Weight in Pounds)

Type of Truss	Top Chord	Bottom Chord	Verticals	Diagonals	Gussetts, Fillers and Splices	Rivet Heads** or Welds	Top Bracings	Bottom Bracings	Portal and Sway Bracings	Floor System*	Pivot and Ring Gir.	Control House and Miscellaneous	Total
Riveted	75632	75496	61417	63724	46573	4765	42508	20839	28779	222003	85423	31851	759,000
Welded	48632	47520	50550	55000	21940	1398	25320	14928	20955	203904	32154	31851	569,782
Difference in favor of weld	27000	27976	10865	8724	24633	3367	17188	5911	7824	18099	53269	..	189,218
Percent	35 7	37	17 7	13 7	53	70	40 5	28 3	27.2	8 2	62 4	..	25.5

*) Floor system is included—the girders, stringers, details.

**) In Riveted Truss welding was used in "built-up" members and in connection the filler plates to Gusset Plates or members. All welds were shop weld and distributed as follows

	3/16"	¼"	5/16"	⅜"	
Length	24'	666'	1209'	69'	= 1968'
Unit wgt.	.10	.20	.25	.35	
Total wgt.	24#	133#	302#	24#	= 483#

Table V—Estimate of Swing Bridge (287 feet–3½ inches)

2 @110 foot = 220 foot 0 inches clearance 26 foot 0 inches Roadway + 2 @2 foot Sidewalks	
1. Structural steel—569,780# @8½c*	$ 48,431.30
2. Machinery (569780 x .12) = 68370# @50c	34,185.00
3. Floor: I-beam-lok armored slab (28.17 x 287.3) x 15.5# = 125 x .07 = 8750.00 Concrete 75c.y. @18.00 = 1350.00 Handrail 574′ @1.50 = 860.00	10,960.00
4. Fender and piles	1,270.00
5. Operator's house	23,000.00
6. Draw rest	30,212.00
7. Fender round pier	17,282.00
	$165,340.30
Contingencies 15%	24,801.04
	$190,141.34

Cost of present structure—$219,275.00

The saving in favor of using the welded trusses = 13.3%

The saving in favor of the welded trusses for swing bridge in place of semi-welded present trusses $= \frac{\$68310 - 48431}{68310} = 33.3\%$

*) Unit prices based on the actual competitive bidding 1940, on which the contract was given for present semi-welded trusses and estimate was done. Only unit price for structural steel for welded trusses was reduced on ½ cent per pound, because a tremendous amount of shop layouts, details and handling of material were eliminated.

The direct saving in metal amounts to 189.218 lbs. or 25.5 percent.

The saving in cost in favor of the welded trusses for swing bridge in place of semi-welded present trusses equals to 33.3 percent.

The total saving in cost of the whole structure, using welded trusses, amounts to 13.3 percent.

The itemized weight calculations for the two designs are not included in this paper, because its volume will increase the size of the paper without justification.

But Table I has the comparative weight of each group of members separately and it is in this table clearly shown in which group the arc welding is mostly effective. The gusset plates and filler plates drop to 53 percent, the welds save 70 percent as against the riveting. The saving of weight of pivot girder and ring girder needs a special explanation:

By inspection of details of riveted pivot girder it is seen that a great amount of steel used as construction material due to riveted method is purely waste weight. To that waste weight belong:

1) Filler plates under stiffener Ls:
   16 × 1⅞″ Pl. × 8½″ ×4′2″ 66.7′ at 54.2 lbs. — 3620 lbs.
2) Filler plates under central stiffeners:
   4—1⅞″ Pl. × 26″ × 4′2″ 16.7 at 165.8″ — 2770 lbs.
3) Riveted to web stiffener Ls legs:
   56—4″ × ⅝″ × 5′4″ 298.5 at 8.5 lbs. — 2540 lbs.
4) Riveted to web of flange Ls legs:
   8—8″ × 1⅛″ × 30′ 240′ at 30.6 lbs. — 7350 lbs.

16280 lbs.

Pivot Girder:

Dead Load	721.00
1/2 of Operator's house	35.00
	756 kips

Dead load Moment = 756 × 15.875 = 12000 k/1

" " " due to own wgt of Girder = 248k × 15.875/2 = 197 "

Σ = 12197 k/1

Moment diagram: 3797, 5937, 9497 k/1, 12197 k/1; 35', 82.5', 110.8'

Required net Moment of Inertia:

$$I_n = \frac{12197000 \times 12 \times 35.875}{18000} = 292000\ in^4$$

Rivets — 1" φ dia

Section labels: Pl 3/4" × 18"; Pl 1" × 18"; Pl 7/8" × 18"; 2Ls 8 × 8 × 1 1/8"; 2 Pls 3/4" × 7 3/4"; Web Pl 7/16" × 66"; 33 1/4"

Member	Gross Area	Net Area	Igross	Inet
1 Web Pl 11/16 × 66	45.38	33.68	16450	12480
4 Ls 8 × 8 × 1 1/8"	66.92	55.22	65092	46880
2 Pls 7/8" × 18"	31.50	24.06	34000	26000
2 Pls 1" × 18"	36.00	27.50	43200	33000
2 Pls 3/4" × 18"	27.00	20.63	34100	27000
4 Pls 3/4" × 7 3/4"	23.26	16.89	19367	14040
For one Girder	230.06	177.98	212209	159400
For 2 Girders	460.12	355.96	424418	318800

Unit stress (For sections of Girder see dwg. R-5)

$$f_{℄} = \frac{12197000 \times 12 \times 35.875}{318800} = 16430\ \#/\square''$$

$$f_a = \frac{9497000 \times 12 \times 35.56}{318800} = 12800\ "$$

$$f_b = \frac{5937000 \times 12 \times 34.25}{212800} = 11450\ "$$

$$f_c = \frac{3787000 \times 12 \times 33.25}{156800} = 9940\ "$$

Rivet pitch in flanges: Y = 756 + 25k (own wgt) = 781k

$$p = \frac{R \times d}{Y} = \frac{21200 \times 6.05}{781000} = 1.66''$$

Used staggered 1" φ Riv @ 1 1/2" spacing

Pivot Girder:

Dead load ---- 475k; 1/2 of Operator's house ---- 35k } = 510k

Dead load Mom. 510 × 15.875' = 8150 k/1; Mom. due own wgt 13.2k × 1/2 15.875 = 105 k/1 } = 8255 k/1

Use two Girders

Diagram labels: X Y ℄; 3575; 4605 k/1; 8255 k/1; 9.0; 7'-6"; 7'-10"; 7.5'; 18" × 1"; 18" × 2"; 66"; 1/4 32; 1/4 26; 3/8 6-12; 1/4 36; 6'-4 1/2"; 9.0

Section of ℄	Area gross	I gross
Web Pl 11/16" × 66"	45.38	16450
2- Flanges Pls 18" × 2"	72.00	83232
	117.38	99682 × 2 = 199364 in⁴

The center of gravity is 35" up from the bottom

The maximum fibre stress of flanges is

$$f_s = \frac{8255000 \times 12 \times 35}{199364} = 17350\ \#/\square in$$

At Section Y the moment is 4605000 #/1, and

Section		
Web Pl 11/16 × 66	45.38	16450
Top flange 18" × 1"	18.00	28382
Bott " 18" × 2"	36.00	27617
	99.38	72449 × 2 = 144898 in⁴

The center of gravity is 28 3/4" up from the bottom

The maximum fibre stress of the top flange is:

$$f_s = \frac{4605000 \times 12 \times 40.25}{144898} = 15350\ \#/\square in\ ^{1)}$$

and the maximum fibre stress of the bottom flange is

$$f_s = \frac{4605000 \times 12 \times 28.75}{144898} = 10950\ \#/\square in$$

1) This stress comes on the double V-butt weld & is a safe tension stress for shielded arc welding (15600 #/□ in.)

Fig. 3. (left). Riveted truss for swing bridge. Fig. 4. (right). Pivot girder for welded truss of swing bridge.

Reduced dead load on Pivot girder (780.8^k for riveted 523.2^k for welded), requires the moment inertia of welded girder smaller and weight of girder reduces tremendously. Also, welded girders were effectively proportioned for the shear and bending stresses without loss of section due to rivet holes. (Compare Figs. 3 and 4).

The same analysis applies to the ring girder.

It is typical case in comparison of riveted and welded girders of big sizes.

For average size and loading the saving in favor of welded girders runs about 30 percent but in this case it goes up to 62.4 percent. It already shows the advantage of the arc welding in structural connections.

Economic Aspect of the Welded Trusses in Bridge Construction—The direct saving in metal of welded trusses (25.5 percent) and the saving in cost (33.3 percent) cannot be discussed in this case in terms of mass production because this kind of bridge is used very seldom. According to the author's knowledge an average of only four highway swing bridges are yearly built in the United States of America.

Mr. O. E. Hovey, in his "Movable Bridges", (Vol. 1, p. 40) gives data on swing bridges for the period of 1903 to 1923, where he says:
"174 Railway and 43 highway swing bridges were built in this period by one manufacturer and it is believed that they fairly represent the average practice in the United States for the past twenty years."

But the same saving (minimum 20 percent) in metal due to use of the welding process in bridge construction can be expected in any truss bridges and this fact was proved many times in the last ten years in the designs and actual bridge constructions.

From that point of view, the effort is made to approach the present problems in the national scale.

The annual volume of bridge construction in the United States of America obtained from the contracts reported by the Engineering News Records:

Bridges:	1936	1937	1938	1939	1940	1941
Public	173,749	125,230	126,969	143,128	108,050	105,830
Private	14,067	7,895	7,664	7,503	12,101	5,798
	187,816	133,125	134,633	150,631	120,151	111,628

Average $145,270,000 per year.

In this table three 000 omitted, and also includes all types of bridges.

During those years structural steel used in bridge construction, according to the American Institute of Steel Construction:

Bridges:	1936	1937	1938	1939	1940	1941
Highway	526,536	420,093	359,000	377,000	392,000	221,000
Railway	67,792	40,229	32,000	51,000	48,000	93,000
	594,328	460,322	391,000	428,000	440,000	314,000

Average 462,000 tons per year.

In this table weight given in tons and includes all types of bridges.
1941 data in both tables omitted in deriving average sum, because this year already was affected by the present war conditions.

Unfortunately, no general statistics are available as to the tonnage by bridge types as girders, trusses, etc.

The author's study of the bridges built by the highway department of one large state from 1931 to 1942 gives the following comparison:

Girder Bridges .... 26,262,700 lbs. or 56 percent
Truss Bridges .... 20,528,000 lbs. or 44 percent

Now using the above shown statistics the following example is derived to show the possible savings in national bridge construction program as a result from the use of arc welding:

Structural steel in bridge construction per year ....462,000 tons
Structural steel in truss bridges per year —462,000 x .44 ....203,280 tons
Estimated saving due to the use of arc-welding—203,280 x .20 .... 40,656 tons
Using pre-war price for structural steel in-place—40,656 x 150 ......$6,098,400 per year

That gives 4.2 percent of saving for total amountof money spent per year on bridges in the United States.

Regardless of approximations and lack of the statistics, available on the subject, it is evident the use of arc welding in truss bridge construction can save a considerable amount of money.

Performance and Service Life—The method of construction of swing bridges (assembly starts from center of bridge and symetrically proceeds to ends) allows a free expansion of welded members and by that minimizes locked-up stresses; there are all chances to expect the performance of all welded trusses not only as satisfactory as the riveted, but better owing to the fact that there cannot be expected any loosened rivets under traffic, which are so important, especially in railway swing bridges. As was mentioned before, the absence of rivet heads creates the smooth nice surfaces of members and increases the life of the bridge by the elimination of many "starting points" of rusting around rivet heads and considerably saves maintenance expenses on painting. Also reduced weight of trusses and machinery will yearly decrease maintenance and operation expenses.

Social Benefits, Conclusion—Any progressive civil engineer will agree with the statement made by Mr. Wellington in his "The Economic Theory of the Location of Railways":

"It would be well if engineering were less generally thought of and even defined as the art of constructing. In a certain important sense it is rather the art of not constructing or to define it rudely but not inaptly, it is the art of doing that well with one dollar which any bungler can do with two after a fashion."

Refusing to use arc welding in steel construction in the present time of war, when saving of steel is so important for victory, deprives a designer from a rank of the civil engineer to a bungler and strips the United States of America of at least 20 percent of structural steel and about 25 percent of money spent on bridge construction. On these savings of material and money could be built more bridges for the defense of our country.

Arc welded steel structures are not revolutionary but are an evolutionary step in steel industry and could not stop. It is an inevitable fact. For the benefit of the United States, for the victory of our country and allies, and in the future for the after-war recovery building program for the whole world benefit, arc welding should be used on a larger scale than it is used now.

Chapter VI—T-Beams for Residences

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Edward J. Slygh

Subject Matter: Development of an arc welded beam which has been accepted and used by architects. Design computations and working tables are included.

During four years that the author was employed in the engineering department of a structural steel fabricating company, one of his duties was to take care of the sales of fabricated steel to local customers.

One particular group of local customers, the home builders, was continually bringing in requests for what they called a T-beam, — something to hold up the ends of joists in a house remodeling where a partition was being removed and the owner had said that he wanted "no dropped beam" in the ceiling of his new living room.

When such requests came in, knowing that the standard rolled T-section is not strong enough to span the opening or to carry the required load, the policy of the department had been to furnish two angles bolted together and of sufficient size to carry the indicated load.

Things went along smoothly until one day a builder came in for "one of those T-beams" with such a loading on it that the required section for a 15′-0 span was 2 angles 8 x 6 x ¾. It weighed over 1000 pounds and cost about $40.

The author expected loud protestations from the builder but none were forthcoming as he had already warned the owner of the high cost and the owner had said that it would be worth whatever it cost to have his house the way he wanted it.

The order was placed, the beam was fabricated, the owner was pleased, the builder strained his back erecting the beam, and the author had a firm resolve to look into the design of a T-beam using his knowledge of structural design, rolled shapes, and arc welding.

Method of Attack and Result—The problem was to select the rolled structural shape or combination of rolled structural shapes which would have,

a) Minimum width of top flange.
b) Wide enough bottom flange to carry wood joists on both sides of the vertical web.

The following were some of the combinations considered:

			Remarks
Angles:	double, back to back		Poor distribution of metal.
Channels:	double		" "
	single and plate		" "
Beams:	single WF, narrow top flange by cutting		Not flexible enough.
	single I, with plate		Poor distribution of metal.
	split WF		Not enough metal in top flange.
	split WF, with one bar		Good design section.
	split WF, with two bars		Too much welding.
	split WF, with angle		Difficult fabrication.
	split WF, with bar channel		Too few suitable channel sections.
	split WF, with pipe		Too little metal in top flange.
	split WF, with square		Good design section.
	split WF, with round		Good design section.

As the result of this study it was decided to compute the properties of cross section of the split WF beam with bars, squares, or rounds attached to the web by arc welding to form the top flange of the section.

Design—There were four steps taken in the design of these unsymmetrical sections,

a), properties of the cross section.
b), amount and distribution of weld to connect bar to split WF beam.
c), work up tables for selection of proper section for various loads, spans, and depths of section.
d, check bearing of wood joists on bottom flange.

The first steps are most simply explained by referring to Fig. 1 where the calculations for a typical T-beam are shown. Since these calculations

DESIGN OF T-BEAM

PROPERTIES:

TOP FLANGE: BAR - 2 - 3/4

WEB & BOTTOM FLANGE: 1/2 - 12WF 25#

A = 1.5	
d = .75	
x = .375	
I = —	
A = 3.69	5.19
d = 5.94	6.59
x = 1.26	2.73
I = 11.0 in⁴	38.2 in⁴
Sm = 2.35 in³	9.65 in³

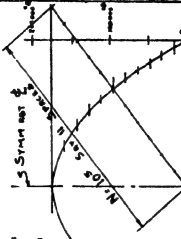
COMBINED SECTION

TABLE

SECTION	#/FT	A	x	ax	(ax²	+ Iₒ)	- I_NA	- Ax̄²
1/2 12WF 25#	12.5	3.69	1.26	4.7	5.9	11.0	76.9	5.19
BAR 2 - 3/4	5.1	1.5	6.32	9.5	60	—		x̄² 7.45
	17.6	5.19		14.2		65.9	-38.7	-
		x̄ =	2.73			76.9	38.2 in⁴	= I
		x top fibre =	3.92	Sm = 38.2/3.92	=		9.65 in³	Sm

WELDING:

N = M / (k·d) = 175,000 / (3000 · 5.56) = 10.5

WHERE
N = NUMBER OF WELDS ONE FLANGE
M = BENDING MOMENT = WL/8 = 8290·14·12/8 = 175 000#
k = VALUE OF SPOT OF WELD = 1/2" @ 2000 = 3000#
d = DISTANCE BTWN WELD & BOTTOM FLANGE = 5.56"

LOADINGS:

FROM WL·12/8 = f I/c ∴ W = f·Sm·8/(L·12)
IF f = 18 000#/□" & L = 1.0 ∴ W = 12000 · Sm / SPAN
ALSO MAX SPAN TO KEEP Δ = L/360 = 3.58 · n
WHERE n DIST OF NA TO EXTREME FIBRE

EXAMPLE:
{1/2 - 12WF 25#, BAR - 2 - 3/4} Sm = 9.65 in³, n = 3.92
MAX SPAN = 3.58 · 3.92 = 14.5
W ALL UNIF. SPAN 14.0 = 12000 · 9.65 / 14 = 8290#

N = 10.5 SAY 11 SPACES
SYMM ABT ℄

THEORETICAL SPACING OF WELDS

T BEAM {1/2 12WF 25, BAR 2 - 3/4} = 14.0

ACTUAL WELDING DIAGRAM

BEARING - WOOD JOISTS:

R ALLOWABLE 2" JOISTS = 1 5/8 · 2 1/4 · 325 = 1190#
R 2" JOISTS 16" c/c 20.0 SPAN 50#/□' LOAD = 1.33 · 20 · 50 / 2 = 667#
R 2" JOISTS 24" c/c 20.0 SPAN 50#/□' LOAD = 2 · 20 · 50 / 2 = 1000#

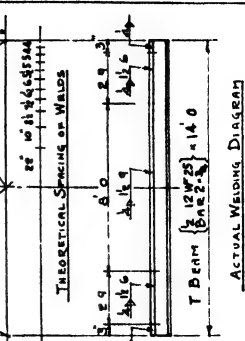
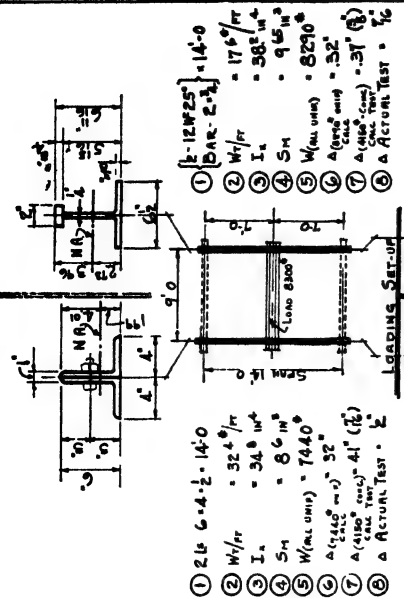
* CARNEGIE-ILLINOIS "POCKET COMPANION" - 24TH EDITION

LOADING	DEFLECTION: DOUBLE ANGLE BEAM	DEFLECTION: T BEAM	REMARKS
0	0	0	NO LOAD
4150#	1/2"	7/16"	FIRST LOAD
0	1/16"+	0	FIRST LOAD OFF
4150#	1/2"	3/8"	FIRST LOAD
8300#	7/8"+	7/8"+	DOUBLE FIRST LOAD
4150#	1/2"	7/16"+	FIRST LOAD
0	1/16"	1/16"+	NO LOAD

Fig. 1, (left). Design of T-beam. Fig. 2, (right). Test results.

were a bit tedious, the number of split WF beams considered at the outset was limited to two,—12WF25 and 14WF30 with various bars, flats and squares.

It was then a matter of working up tables from which a section of T-beam could be selected, given the span and loading.

Estimated Savings in Weight and Cost[1]—For the purpose of this comparison we will continue to consider the section which was designed above,—

Weight:

	Unit Wt.	Total Wt.
2 Ls 6 x 4 x ½ x 14'-0 / 10 Bolts ¾ x 0'-2	32.4 lbs. per ft.	453 lbs.
½ 12WF25 x 14'-0 / 1 Bar 2 x ¾ x 14'-0 / 72" Weld ¼"	17.6 lbs. per ft.	246 lbs.
Saving in Weight by arc welded design		207 lbs.

Cost

Double Angle			
Shop			
Mark and			
Punch	12ϕ @ .02 =	.24	
Bolt	12ϕ @ .01 =	.12	
		.36	
Burden		.39	.75
Material 453 lbs. @ .036 (Incl. extras)			16.20
Paint 453 lbs. @ .0015		.70	
Draw		1.00	
Local delivery		1.25	2.95
			$19.90

T-Beam			
Shop			
Burn WF	14' @ .035 =	.50	
Weld	6' @ .07 =	.42	
Fit	6' @ .06 =	.36	
		1.28	
Burden		1.42	2.70
Material 246 lbs. @ .038 (Incl. extras)			9.30
Paint 246 lbs. @ .0015		.40	
Draw		2.00	
Local delivery		1.00	3.40
			$15.40

Saving in Cost by arc welded design .... $ 4.50

As these two sections were actually fabricated in the shop for testing, it was possible to get a check on the actual shop cost and the percentage of saving in cost as shown in the following table:

Description		Wt. per Ft.	Unif. Load Lbs.	Cost (S.P.)			% Savings	
				Total Wt.	Unit Cost	Total $	Wt.	Cost
Estimated	Double Angle	32.4	7440	453	$4.40	19.90	46%	23%
	T-Beam	17.6	8290	246	6.25	15.40		
Actual	Double Angle				4.19	19.10		
	T-Beam, incl. straightening				6.08	14.95	....	22%

In order to get a true picture of the savings in both weight and cost for the entire range of the T-beams expected to be encountered, sections were designed for various spans and loadings. These two items of comparison are presented in the following table.

[1]In this and all following discussions of fabricator's costs these average 1940 figures will apply:

Shop Labor	.75c	per hour
Base Steel Price (Warehouse)	.0355c	per pound

Comparisons of Weight and Cost

Description	Weight per Foot	Uniform Load Lbs.	Cost			% Savings	
			Total Weight	Unit Cost	Total Cost	Weight	Cost
2Ls 5 x 3½ x ⅜ x 12′-0	20.8	4,590	250	$5.15	$12.90		
{½-10 W.F. 21° / Bar-1½ x ½} x 12′-0	13.1	4,640	157	6.45	10.10	37%	14%
2 Ls 5 x 3½ x ½ x 12′-0	27.2	6,000	326	4.90	16.00		
{½-12 W.F. 25° / Bar-1½ x ½} x 12′-0	15.1	5,950	181	6.55	11.85	55%	26%
2 Ls 6 x 4 x ⅜ x 14′-0	24.6	5,690	345	4.90	16.90		
{½-12 W.F. 25° / Bar-1½ x ⅝} x 14′-0	15.7	5,820	220	6.25	13.75	36%	19%
2 Ls 6 x 4 x ½ x 14′-0	32.4	7,440	453	4.40	19.90		
{½-12 W.F. 25° / Bar-2 x ¾} x 14′-0	17.6	8,290	246	6.25	15.40	46%	22%
2 Ls 7 x 4 x ⅜ x 16′-0	27.2	6,600	435	4.50	19.60		
{½-14 W.F. 30° / Sq.-1-sq. in.} x 16′-0	18.4	6,700	294	6.25	18.35	32%	7%
2 Ls 7 x 4 x ½ x 16′-0	35.8	8,700	573	4.50	25.80		
{½-14 W.F. 30° / Bar-2 x ¾} x 16′-0	20.1	9,150	322	5.95	19.20	44%	25%
2 Ls 8 x 4 x ½ x 18′-0	39.2	10,000	706	4.25	30.00		
{½-16 W.F. 40° / Bar-2 x ¾} x 18′-0	25.1	10,100	452	6.00	27.00	36%	9%
2 Ls 8 x 4 x ¾ x 16′-0	57.4	16,400	920	4.00	36.80		
{½-12 W.F. 40° / Sq.-2-sq. in.} x 16′-0	33.6	16,200	538	5.45	29.20	41%	20%
2 Ls 8 x 6 x ½ x 19′-0	46.0	10,100	875	4.25	37.20		
{½-18 W.F. 47° / Bar-2 x ¾} x 19′-0	28.6	11,600	543	5.45	29.50	38%	20%
2 Ls 8 x 6 x ¾ x 15′-0	67.6	18,500	1,027	3.95	40.20		
{½-14 W.F. 30° / Sq.-2-sq. in.} x 15′-0	28.6	18,100	431	5.60	24.00	58%	40%
					Average =	42%	20%

From a study of the variation of the percentage of savings of weight and cost of the arc welded T-beam over the bolted double angle beam, it was decided to speak of the average savings as follows:

Saving in Weight ....35 to 50%
Saving in Cost ....10 to 25%

Tests—At about this point in the development of the T-beam, it was felt that the figures indicated that there were several good features to it and that before proceeding further it would be wise to make up a full size double angle beam and a T-beam and run tests on them.

The primary reason, of course, for the tests was to check the action of the T-beam under various loads. Other reasons were to check the shop costs and procedures.

Fig. 2 gives information about the two tested sections such as size, dimensions, properties of section, loads, loading order, and the resulting

deflections, both calculated and actual. Photographs, Figs. 3 and 4, indicate the general arrangements of the tests.

After the completion of the tests, there was no indication of failure in either beam as a unit or of any of its parts.

Progress:[2]

1. T-Beams in Air Conditioned Homes—There were two original uses contemplated of the T-beam,—

a) in the remodeling of residences to permit an unbroken ceiling where two rooms were being made into one by the removal of a common wall partition,

b) in the basements of new homes to give additional head room or to lessen the cost[3] of the basement by decreasing the depth of excavation and concrete wall by the amount of depth of the beam ordinarily used under the bottom of the joists.

However, more homes were now being air conditioned,—in some, this was only a conditioned warm air system, while in others the more elaborate outlay of cooling the air was included.

Fig. 3. (left). General arrangements for tests. Fig. 4. (right). Another view of test.

[2] In checking over the actual shop costs of the second year for a confirmation of estimated savings in items discussed under this heading, the figures failed to show anything conclusive in the way of progress for the following reasons:

a) Increase in labor and material costs.

b) Decrease in amount of steel used in homes.

c) Large volume of defense plant work which shunted shop attention to other channels.

Frankly, even after adjustments were made for increases in labor and material costs, no improvement in shop costs could be noted due to quantity production or in other means of lowering the actual costs which certainly would have shown up in normal times.

[3] Example of saving in cost effected by reducing basement (25x32) depth 6 inches, that is, the depth of the ordinary 6-inch I-beam:

Excavation ....$25 \times 32 \times .5 \div 27 = 15$ cy @ .75¢ = $11.00
9″ Concrete Wall $(25 + 32)\ 2 \times .5 = 58$ sf @ .50¢ = 29.00

Total Saving $40.00

This involved sheet metal duct work and architects and builders were being confronted with the problem of introducing the ducts at the bottom of the interior wall partitions which were generally supported directly over basement beams.

This arrangement required that the T-beam section be held to a depth which would permit the passage of the duct between the top flange of the beam and the underside of the sub-flooring.

In the design of this section, then, with the overall depth kept constant, the T section of the beam became something less than the full ½ WF and there arose the need for some convenient form of arriving at the properties of this section for various depths. This need was met by graphs which were worked up for some of the more frequently used beams.

Using values obtained from these curves, the properties of the combined sections were calculated and from this information series of constant depth T-beams were designed.

Taking for example, the ½ 12WF25 and bar 2 x ¾, good for 110,000 pounds uniform load on one foot span, we find that the top flange of the constant depth beam should be increased to a bar size of 2 x 1 to carry approximately the same load. This will add 1.7 pounds per foot to the weight of the beam. It will be noted, though, that this weight is not prohibitive and that the speed decreases in the lighter sections.

However, the cost will be greater due to the added weight, slightly heavier welding, and the additional burning cost in the splitting of the beam sections. Therefore, a comparative study was made of the weight and cost on a lineal foot basis of the T-beams using ½ WF, Pc WF, and the bolted double angle beam.

2. Continuous Beams—After builders had been buying T-beams for several months and had become more familiar with its use, it was suggested that continuous beams be used in the basement.

Generally there were two beams required here, spanning the shorter dimension of the basement, near the center of the house and providing a base for the main stair framing.

Sometimes each of these beams was supported on one column and other times on two columns. In the latter case in the design of the section it was possible, due to continuity to reduce the section somewhat, from ⅛ Wl to $\frac{1}{10}$ Wl. (Not to $\frac{1}{12}$ Wl because of the fact that the beams were only simply supported at the wall reactions).

At any rate, this was only a small consideration in comparison to the improvement in both the shop and field due to handling longer lengths.

In the shop there were only two finished pieces to handle compared to four or six and apparently there was no great difficulty experienced in handling the longer lengths.

In the field, since these basement T-beams were used a little above grade, the continuous beams could be slipped off the delivery truck and into the approximate location on the building foundation, thereby saving some erection expense. In addition it was felt that the continuous beams afforded a stronger and more rigid base on which to construct the interior house framing. See Figs. 5 and 6 for photographs of these beams in the shop and field.

3. Stock Lengths—As further progress in shop fabrication, T-beams of the most called-for sections are now made up in stock lengths of 40 and 60 foot lengths.

This procedure makes the T-beam a more desirable item for the shop because it enables them to use the fabrication of these stock lengths for fill-in when the volume of work in the welding department is low.

Shop fabrication of stock lengths of T-beams not only improves the chances of reduction of shop cost but also permits quicker delivery of a relatively highly fabricated product.

Conclusion—a) The proportionate savings in percentage of the T-beam compared to the double angle beam is,—

Weight	35 to 50 Per cent
Cost	10 to 25 Per cent

b) The annual gross savings to the home building industry[4] by use of the T-beam in all units built in a year would be,—

Home Remodelings	$ 800,000
New Homes, under $7,000	6,860,000
New Homes, over $7,000	550,000
Total Annual Gross Saving	$8,210,000[5]

	1940	1941	Annual Average
[4]New homes, under $7,000	*203,000	*287,000	245,000 Units
New homes, over $7,000	*46,000	*59,000	52,500 Units
Total Annual Average			297,500 Units
Remodeling, using T-beams (297,500 × 60% Estimated)			178,500 Units

(*These approximate figures are based on information furnished by the F. W. Dodge Corporation).

[5]Home Remodelings — No. of units, 178,500 @ $ 4.50 = $ 803,250

Comparison

2 Ls 6×4×½ — 32.4#/ft×14′=453#@$4.40= 19.90

½ 12WF25)
Bar 2×¾) — 17.6#/ft×14′=246#@ 6.25= 15.40

Saving per Unit..........$ 4.50

New Homes, under $7,000 — No. of units, 245,000 @ $28.00 = $6,860,000

Comparison, Home 25 × 32, one beam 32′-0″.

Save 6″ of basement (See Sub-note 3)..........$40 00

(½ WF)
T-beam 15.9#/ft×32′=510#@$6.00=30.60
Std. 6″ I 12.5#/ft×32′=400#@ 4.70=18.60 —12.00

Saving per Unit..........$28.00

New Homes, over $7,000 — No. of units, 52,500 @ $10.50 = $ 551,250

Comparison, Home 30 × 40, two beams 30′-0″.

JL-beam 32.4#/ft×60′=1950#@$4.40 = $86.00

(Pc WF)
T-beam 19.3#/ft×60′=1160#@ 6.50 = 75.50

Saving per Unit..........$10.50

c) Some advantages which derive from the use of the T-beam are,

To Whom	Feature of T-Beam	Manner of
Nation	Light weight	Conserves natural resources.
Industry		
Labor	Greater amount of labor.	Gives more employment.
Manufacturers	Splitting W.F. Welding T-Beam	Increases use of oxy-acetylene burning equipment. Increases use of arc welding equipment.
Fabricator	High unit price with less steel. Light weight Fills special need	Allows fabricator more profit. Saves handling time and equipment. Stimulates sales to regular customers. Brings in new customers.
Architects	Special shape	Gives unobstructed basement ceiling. Accommodates air conditioning ducts.
Builders	Less framing depth Special shape	Reduces depth of basement excavation and wall. Permits unobstructed ceilings in remodeled homes.
Home Owners	Lower cost Strength	Saving in total cost of home. More efficient use of steel framing.
Designer of T-beam	Development of an idea	Experience of selling an idea to, (a) Management of fabricating company. (b) Architects, builders, and owners.
	Development of T beam	Assisted author in securing a position offering greater opportunities with another employer.

d) Finally—In thinking through the advantages that accrue from a simple arc welded beam used in homes, one comes to the realization of the positive forces from which arc welding derives its potential for making a better world in which to live.

Arc welding not only conserves national resources and affords labor more employment, all at a less cost to the ultimate consumer but it also contributes to the development of those people who work with it, who study it, and who try to understand it.

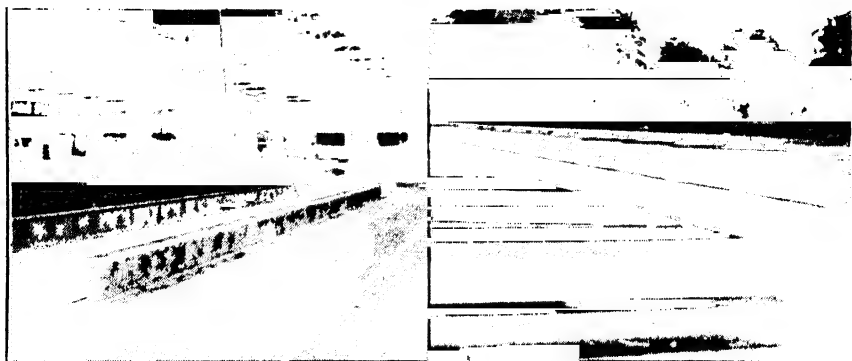



Fig. 5. (left). Shop view of T-beams. Fig. 6. (right). Field view of T-beam.

Chapter VII—Steel Framing for Residences

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Subject Matter: Design analysis based on a residence, said to be the first all welded steel framehouse. Two ideas are presented: (1), a clip connection designed to make a permanent field connection; (2), a wedge connection between column and beam.

This paper describes and analyzes the construction of a 100 per cent all welded, structural steel frame for buildings of all designs including homes. The scope of this paper will be an attempt to present the practical side and not the technical science of welding.

Outgrowth of the Skyscraper—As everyone knows, the rigid steel frame which made the modern skyscraper a possibility, was originated more than a half century ago, but the universal tendency of the human minds to run in grooves and to think of things only from one point of view, delayed the application of steel framing to smaller buildings. Architects, builders and home owners kept thinking of steel framing as a construction very desirable on many-storied buildings. As so often happens, once the new method is applied, everyone asks, "Why didn't we think of this before?"

The First Real Advance in Home Building Methods in Hundreds of Years—In 1902 America's first large steel-framed office structure, the Flatiron Building in New York City, opened a new era in American Building design. The skyscraper became a reality.

Most of us know that the field of residence construction has failed to keep pace with the rapid progress in the commercial field. Yet all the time the logical and practical advantages of low cost, all welded, steel framework for homes were only waiting for someone to see and apply. Now, with our improved structural steel, all welded, steel framing, the first real advance in home building methods in hundreds of years has been made.

Engineering in Home Construction—If the manufacturers of automobiles had not brought steel into the framework of the modern car, there is little possibility that the average American could afford one. What was once called a luxury, is now almost a necessity. By the use of accurate steel framing, it was possible to detail and fabricate all the parts that go into the car. Every piece of material that goes into the car is fastened to the frame, directly or indirectly.

Production Units—Steel framing in a home, as in an automobile, makes

Fig. 1. Erection clip.

it possible to prefabricate all the parts that go into the home. Engineering science is the answer to reducing the cost of home construction, and this is possible only through the use of a rigid and accurate structural steel framework, that can be erected with a hammer having no bolts or rivets.

Fifteen Years of Research Work—For the past 15 years there has been much interest, study and development of steel framing for residence construction. When the idea was first brought to the attention of the public by the designer and inventor of the steel framing and systems, the idea was scoffed at as being "visionary" and "ridiculous".

The United States Steel Corporation made a survey of steel framing and construction systems. Nearly one hundred different types of construction were studied. At the completion of their survey in June, 1932, 56 designs were published in a book for circulation within the Corporation, including the R. R. Schwartz House, The Colorado Fuel and Iron Co. house, and the Steel-bilt Homes, Inc. houses, all licensed under pending and granted patents.

A book was published later for the public entitled "Steel Framing for Small Residences." The R. R. Schwartz residence designed by the author was chosen as an illustrative example and given 14 pages of discussion. Steel tables were set up based on our design. This system has been developed into commercial building of all kinds. The Schwartz residence was the first all welded house.

To quote Roger Babson, "Two industries are one of our greatest hopes for solving the unemployment question. The industrial revolution has given America her standard of living. I am convinced that even greater progress lies ahead. Prefabrication will some day force building to drop its medieval "hammer and saw" customs but so far results have been disappointing. The poor comparison of a hand-made $10,000 house with a factory-made $1,000 automobile means prefabrication will win".

To quote President Roosevelt, "It is estimated that an average of 600,000 to 800,000 dwelling units ought to be built annually over the next five years to overcome the accumulated shortage. If the building industry is to play the vital part that it ought to have in our economic system, it must do it in the characteristic American way. It must develop, as other great industries have developed the American genius for efficient and economical large-scale production".

Relief or Jobs—If we are not to be burdened with a relief problem, new industries must be financed and will prove an attractive investment. The United States census for 1930 shows that there were boys between the ages of 15 to 17 years old, numbering 24,366 in Cleveland, and 28,098 in Cleveland's four suburbs, making a total of 54,484 boys who probably graduate from school or quit school to go to work, plus boys graduating from college. Each year we will have the same situation. Two things can happen, they get jobs or else—. Relief is the only other answer. It is new ideas that will provide the necessary jobs.

Where Are We to Find Tradesmen?—The production units will solve this problem.

Unions have been working on the policy of "No apprentices and we can demand higher wages". In ten years death has taken young and old members of the union. Then again, many have found employment in other fields. For the past two years, we have felt the shortage of men in Cleveland. The time required to train an apprentice is four years.

The Cleveland Union Membership

Carpenters' Union	1928 — 6,000	1938 — 4,000
Bricklayers' Union	1928 — 2,200	1938 — 1,100

Past Experience in Building Construction—Records of Cleveland Building Construction show that there were times when we were compelled to pay as high as twenty cents per hour over Union scales to get men. All we were doing in those days, was robbing Peter to pay Paul. Building costs rose so high that people would not build. Naturally, causing a depression in the building industry. All welded framing and production units are the answer to solve our labor problem.

Union Scale Comparison in Field and at Shop

	Field	Shop
Carpenters	$1.37½	60 to 80c
Iron Workers	1.62½	60 to 93c
Painters	1.50	65c
Metal Workers	1.37½	60 to 80c
Common Labor	.90	40 to 65c

The Economies of Production Units—It should be remembered that the production units produced by machinery and in large quantities would result in a very much greater saving than that shown in the above comparison of shop and field costs. It should also be noted that due to large quantity and machinery production, there also would be a very great saving in the purchasing of materials.

Speed of Construction—This increased proportion of shop work done, obviously will reduce the labor and cost on the job. Under existing building methods, at least three months time is required to complete a house. It is estimated that a production home should be completed in one month.

Gold Mine of Wages—The richest gold field in the world is that of South Africa. During its productive life-time, it has so far produced a total value in gold of approximately seven billions of dollars.

When the automotive pioneers—Ford, Leland, Briscoe, Durant and others—first discovered gold on the plains of Michigan, there was not a dollar's worth of employment or of wages available in the industry. It started from scratch. Since 1900 and including 1937, there has come from that modest little discovery a golden flow of wages aggregating the stupendous sum of 84 billions of dollars! Wages directly traceable to the automobile to say nothing of dividends paid stock-holders.

There is, today, a greater gold mine of wages to develop and that is the production of homes.

Engineering science that has given the automobile great success will do the same for home construction.

A detailed survey recently made by a trade research committee drawn from Subsidiary Companies of United States Steel Corporation for the purpose of investigating the potential demand for steel in residence construction was completed in 1932. Nearly 100 different systems of construction were studied. A number of residences built in accordance with these systems were inspected by representatives of the committee.

The following detailed analysis is based upon a study of the design of the R. R. Schwartz residence. This particular residence was selected as the illustrative example for three reasons:

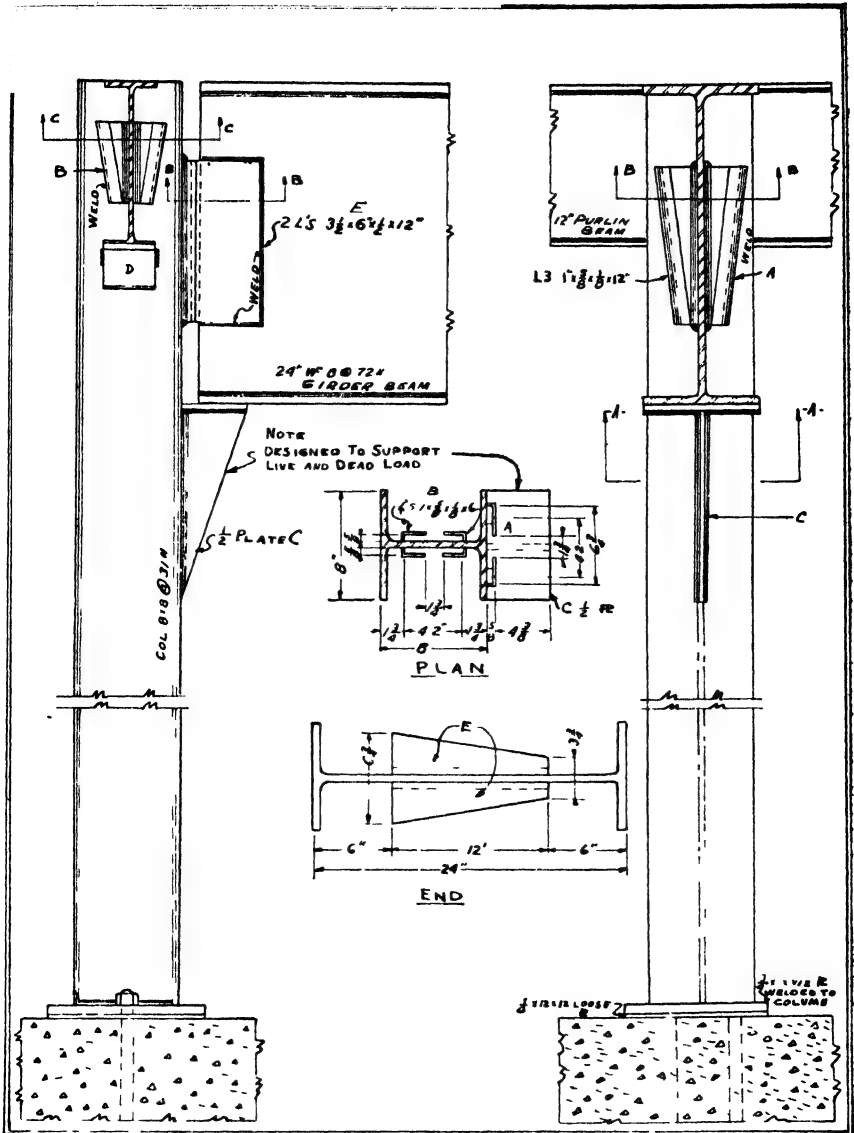
1, sufficient information was available upon which to predicate a design.
2, the structure received nation-wide publicity while it was being erected.
3, it is reported to have given satisfactory results.

Stud Analysis—The typical studs were American Standard Channel Sections, 3 inches deep, weighing 4.1 pounds per foot.

d = 3″ b = 1.41″ t = 0.17″ Area 1.19 Sq. In.

Properties	1	S	r
Major 1–1	1 60	1.10	1.17
Minor 2–2	0.20	0 21	0.41

Longest studs are 10 ft. long. 1 = 120 in.

Fig. 2. Wedge-weld steel frame.

While the partial fixity at ends due to welding is advantageous its effect is too elusive to warrant any allowance. The strut is, therefore, assumed to have both ends free. It is good practice to use the greatest length as a criterion for designing all typical studs.

Major Axis $\frac{1}{r} = 102.5$

Using A. I. S. C. formula: Working stress = 11.4 kips per sq. in. Using

Ruler formula: Ultimate Stress $\frac{\pi^2 Er^2}{l^2}$ = 26.7 kips per sq. in. Factor of Safety = $\frac{26.7}{11.4}$ = 2.35

As beams to resist direct wind load, 3-inch channels 4 feet apart, are evidently more than adequate.

Minor Axis $\frac{l}{r}$ = 293. The handbooks give no value for a ratio of slenderness as great as this. Ruler's formula is, therefore, employed.

Ruler formula, Ultimate stress = 3.33 kips per sq. in.

This is the maximum allowable stress on the unbraced section, that is, during construction.

To determine at what intervals (l) the section should be braced so that its minor will equal its major strength.

Minor Length = Major Length $\times \frac{r_2}{r_1} = 120 \times \frac{0.41}{1.17}$ = 42 ins.

In view of the fact that the usual methods of anchorage may not produce absolute rigidity, it seems desirable to reduce the intervals between braces to not over 21 inches.

The following loads per square foot of surface were used in checking the adequacy of the design.

Vertical live loads

Floors — 40 lb. Roof 29 lb. (incl. wind component)

Dead Weight of Materials

As obtained from plans. Some changes therefrom were made in actual construction.

Floors

Item	lb.
Steel, 12.5 ÷ 4	3 lb.
2″ Hollow furred tile	10
2 coats plaster	6
2″ × 4″ pine, 16″ centers	2
1⅝″ Wood, sub-and finished	4
	25 lb.

(Subsequently changed to 2″ Haydite Concrete)

Walls

Item	lb.
Steel	2
4″ Brick Veneer	19
2″ Furred Tile	10
3 Coats Plaster	9
	40 lb.

Roof

Item	lb.
Steel	3.0 lb.
2″ × 8″ pine 24″ centers	2.4
⅞″ wood sheathing	2.6
Shingles	3.0
	11 lb.

4″ Partitions

Item	lb.
4″ Hollow Tile	15
2 Coats Plaster, each side	10
	25 lb.

2″ Partition 20 lb.

6″ Partition 30 lb.

Studs during construction

Provided a straight 3 inch rolled channel section, used as a wall stud, is not over 10 feet long, it may be subjected, prior to anchorage to a working stress of not more than 1.42 kips per square in. This evidently means that no filling material should be placed between or on the floor joists in any floor supported by the stud until after the anchorage material has reached that floor.

Check Critical stud occurs in First Story on Front Elevation next to right corner. Panel equivalent = 5 feet. Floor span = 15 feet. Tributary Floor and Roof area = 5 x $7\frac{1}{2}$ = 37.5 square feet.

Weight of steel floor and roof framing = 3 (37.5 × 3) = 0.34 kips
Assumed Accidental Load .... = 1.00

Total Constructed Load...1.34 Kips

An unbraced 3″ channel is safe for

$$1.42 \times 1.19 = 1.7 \text{ kips}$$

Therefore the unbraced stud will safely carry the steel framework.

Studs in Completed Structure—The same stud, with both flanges securely anchored to adequate adjacent material at least every 21 inches, may be subjected to a total stress, after construction is completed, of 11.4 kips per square inch.

Check: Tributary Floor and roof areas = 37.5 sq. ft.
Tributary 2nd floor wall area = 40.0 sq. ft.

Completed floor and roof load = 4.9 kips
Completed Wall Load = 2.8 kips

Total completed load.........7.7 Kips

3″ × 4.1# Channel is safe for

$$11.4 \times 1.19 = 13.6 \text{ kips}$$

Therefore the braced channel will safely carry the loaded structure.

Critical joist in first floor is 5 feet from rear end of living room.

Span = 15′–3″. Average panel 4′–6″. Tributary area 69 sq. ft.
Allowable deflection due to live load = 1/360 span = 0.51 inch.
Dead load + live load = 1.725 × 2.760 = 4.485 kips, uniformly distributed.

$$\text{Bending Moment} = \frac{71}{8} = 102.5 \text{ inch kips}$$

A 6-inch x 12.5-pound I-Beam was used: $S_1 = 7.3$ $I_1 = 21.8$

$$\text{Deflection due to dead load} = \frac{5}{384} \times \frac{Wl^3}{EI} = 0.217 \text{ in.}$$

Deflection due to live load, 0.347 in.

The live load deflection is therefore within the limit allowed. Fibre stress

$$\text{due to total load} = \frac{\text{B.M.}}{S_1} = 14.1 \text{ kips per sq. in.}$$

Girts—The functions of a girt are:

(a) To tie together the ends of the studs.

(b) To provide a bearing seat for the ends of the floor joists or, in the case of an eaves plate, for the ends of the rafters.

(c) To transfer the loads from the joists or rafters to the adjacent studs.

(d) To act as struts to withstand the pull of the diagonal members of the sway bracing system.

In order to provide for these functions in steel framing, the following notes may be helpful.

(a) It has been found that any member adequate to fulfill its other functions will form a suitable tie section. In order to provide a convenient detail for receiving the ends of the connecting members, it should preferably have an available horizontal surface.

(b) It is usual to space such joists or rafters so as to come either above,

or within a few inches of, the corresponding stud. With this arrangement the bending moment on the girt is negligible. When, however, the respective members are not adjacent (as over a door or window opening), the bending must be provided for. This may be done either by the use of a special stronger section or by the insertion of an additional girt section under the regular one.

In all cases the web of the first girt should be dimensioned by the usual rules to resist buckling due to the maximum vertical shear.

(d) The critical case in a 2-story residence usually occurs at the second floor girts. Here each girt is usually braced in both planes by the connecting joists and studs. It is desirable, however, to transmit the force of the wind on a typical tributary area, and to see that the girt is adequate to transmit it.

Note: The complicated roof framing, caused by the architectural requirement that the roof cut through the second floor ceiling was easily handled by welding. The frame consists of standard rolled steel shapes, cut accurately to length at the Carnegie Steel Co. warehouse and assembled at the site by three steel workers, the connections made with a Lincoln portable arc welding machine.

This construction proved to be very costly and only one house was built by all field welding. The method was not practical for the following reasons:

(1) Vibration of framing due to the iron workers moving steel, welder always making contact with the steel.

(2) Too much scaffolding was required.

(3) Very difficult to line up and plumb.

The design of steel framing we have never changed, only the method of welding.

Fig. 1, Clip Connections

(c) Supporting Lugs—made up with ½-inch plates welded together having four—1¾₁₆-inch holes punched in upper plate.

(d) Supporting angle lugs with two—1¾₁₆-inch holes punched in one flange.

These lugs support the live and dead loads. Welding must be figured out according to the load.

(e) ½ x 4 x 12-inch steel plate four—1¾₁₆-inch holes welded to upper and lower flanges of girder beam.

(f) ½ x 4 x 7-inch steel plate two—1¾₁₆-inch holes welded to upper and lower flanges of Purlin beam.

(a-b) Are clips made from ¾-inch half round, formed to the shape of a U. These clips go through holes in c, e, d and f and are part over the top of e and f.

Clip a and b must be held tight under c and d before bending friction grip will be obtained. We have found from experience that this framing is more rigid than any bolted job and much quicker in erecting.

Base Plates—¾ x 12 x 12 steel plates are welded to the bottom of column forming a base plate ¼ x 12 x 12 steel plate bed over anchor bolts on footing. If care is taken to have these plates leveled right, framing should plumb and line itself.

All commercial job framing should receive about 10 per cent field welding after erection.

This clip method has worked out very satisfactorily on homes and build-

ings such as: theatres, churches, factories and buildings which we have erected. With this design it is possible to even bolt the job if desired. Field welding would not be needed.

Many of our lighter framing jobs had no field welding. The only load the clip takes would be the wind pressure. Clips give the framing the rigidity required.

Wedge-Weld Steel Framing—Fig. 2 is our latest design.

This design is somewhat like the design of a bed illustrated in Fig. 2. Design consists of the following members.

(a) Are 2—5/8 x 1 x 1/8 angles—welded to flanges of columns.

(b) Are 2—5/8 x 1 x 1/8 angles welded to web of columns.

These angles are welded to the shape of a "V". We would recommend a continuous weld on the outside of angles.

(c) Supporting lugs made up with 1/2-inch plates welded together as shown before erection. These lugs support the live and dead loads, having a continuous weld on two sides. C on the flanges of columns.

(d) Support the Purlin beam load and are welded to the welt of column these lugs are 1/4 x 3 x 4 angles. Welding to be figured for the load required.

(e) 2 angles 3/8-inch x 3 1/2 inches x 6 inches. The 3 1/2 inch flanges to be cut the same tapper as the 5/8-inch x 1-inch x 1/8-inch angles, marked A.

These angles are welded to Girder Beam—welding figured according to load. Welding on all the above members can be shop or field welding. Care must be taken to get accuracy for a rigid framing.

After erection the framing to receive 5 to 10 per cent more field welding. Field welding must be done after framing has been lined up and plumbed. No scaffolding will be required with this design.

We do not propose to set up a chart for the size of welds equivalent in shearing strength to rivets of various diameters. We do not believe in sacrificing the appearance of a job to save a few welding rods. A continuous welded job while it might take more welding rods always has the appearance of being a better construction, and will have a greater factor of safety.

Comparison of Welded Construction with Riveted Equivalent—In attempting to substitute by comparisons with the riveted construction, the advantages to be obtained by using welded construction, it must be said in some instances it is going to be quite difficult to give definite conclusions as to the saving in cost resulting from its adoption. However, it is believed that there will be presented enough definite proof supported with actual figures that will be substantiated conclusively the advantages resulting from the use of welding.

Weight—The design shown in Figs. 1 and 2, if fabricated, with riveted or bolted connections, the difference in weight of steel would not vary any. Some engineers might figure by having welded connection that they could reduce the weight of the actual structural steel members. To our way of thinking this would not be good practice. Steel should be figured as if the framing were going to have the old type riveted or bolted connections.

Fabrication—The advantage of the welded job would be that the fabrication could be done on the job in the field.

Small Fabricators—It is possible on factory buildings where they have extra ground space where welding could be done in the field to purchase the steel cut to length direct from the steel mill. We herewith present a schedule of cost for cutting steel at the mill.

Cutting Extras
Friction Saw Cutting Structural Shapes

Beams, Channels, Tees, Zees 3" and over and Angles over 6" either leg.
Angles 6" leg and under—See Shearing Schedule.
Length 5' and over, no charge for cutting.
Minimum Charge 35¢ per item of one length and one size.

Pounds Per Lineal Foot	Under 5 ft. long Per Cut
Under 10 lbs.	$0.07
10.0 to under 17.5	.10
17.5 to under 30.0	.15
30.0 to under 45.0	.20
45.0 to under 65.0	.25
65.0 to under 90.0	.30
90.0 and over	.35

Any section over 10-inch flange—where cut to under 5-inches long—Price on application.

Shearing Charges—Legs of Angles

	10 Ft. and Less	Over 10 Ft. to 20 Ft.	Over 20 Ft. to 30 Ft.
Set-up charge	$1.00 net	$1.00 net	$1.00 net
Per cut for each leg of each angle	.25	.50	.75

Add to the above, the regular length cutting extras. Charge gross weight.

The leg shearing operation is done before cutting to length. Thus 2 angles 5 feet long would be subject to only one 25 cent leg shearing extra since this operation would be preformed on a 10 foot angle.

You will note the mill makes no charge for cutting of steel over 5 feet in length. The minus and plus tolerances required by the mill for cutting will work out satisfactorily for welding. With this method small welding fabricators could enter this field.

Painting—On all steel frame welded jobs painting would have to be done in the field. It is not good practice to try to do any welding on steel that is painted.

Potential Demand—Quoting U. S. Steel, the potential demand in the United States for one and two family residences is 300,000 per year. In this survey 56 systems of steel construction are described. For the purpose of estimating quantities of material required, the average residence is assumed to contain six rooms.

(a), average steel required for economical Framing would be 1¼ tons per room, totaling 2,250,000 tons per year, mostly in the form of small rolled shapes.

(b), there is a growing demand for steel framed residences of individual design.

(c), average steel required for covering all surfaces except floors would be ¾ ton per room, totaling 1,350,000 tons per year, mostly in the form of sheets or strip.

(d), no important domestic demand has yet developed for residences entirely covered with steel.

The present field for the multiple production of identical factory manufactured residences is believed to be comparatively small. This conclusion differs from that of others who advocate the factory-built home.

No proprietary system of construction, having sufficient merit to be considered ideal, has yet been developed, but it is possible that a satisfactory unit system may be evolved by its many investigators.

The most satisfactory framing systems that have been encountered are non-proprietary ones which utilize ordinary rolled steel shapes.

(a) The most promising method of fostering the demand for steel-framed residences is to encourage many architects, builders, and owners to apply the rolled shapes now available to their individual designs.

(b) In order to facilitate the use of steel in the framing of residences, it is recommended that a booklet be prepared and widely distributed, containing information as to the proper use of steel for this purpose.

Extent of Market—It has been estimated by other investigators that, assuming an average of five persons per family, there are 24 million homes (single or multiple) in the United States. Based on replacing two percent of these annually, and allowing for new construction to accommodate the increase in population, the total requirements were estimated to be 780,000 homes a year. In view of the considerable number of people living in apartments and hotels, these investigators reduced this figure to 300,000 new houses per year.

In order to determine whether this estimate should be accepted for the purpose of the present survey, the field has been re-analyzed from a somewhat different standpoint.

Reports compiled by the Dodge Statistical Service and by the United States Department of Labor, covering the number of one and two family residences built in the 37 states east of the Rocky Mountains, are as follows:

Number of Dwellings Built Annually

Year	Costing $5,000—$10,000	Costing $10,000 and over	Totals—1 & 2 Family Houses	
			Dodge	U. S. Department of Labor
1926	127,768	31,379	159,147	230,493
1927	132,803	33,173	165,976	189,495
1928	148,625	36,822	185,447	165,265
1929	112,926	27,655	140,581	117,688
1930	75,057	17,188	89,245	68,843
1931	65,705	13,754	79,459	60,439
Average	$110,481	26,662	136,643	$138,704

U. S. Department of Labor figures are permits issued in 311 cities having a population of 25,000 or over. Total population of these cities—47,091,551.

If the average of the totals (Dodge) be prorated to include construction in the remaining 11 states, the total indicated is 151,673.

At the present time, the population of the United States is approximately 40 percent rural and 60 percent urban. The trend indicates that an increasing proportion of the population is being concentrated in cities. While all of the rural population live in private dwellings, only about two-thirds of those living in cities are assumed to occupy individual homes.

The Dodge total does not include residences in rural districts where the Dodge Company maintains a reporting service, nor does it include any residences costing less than $5,000. It would appear reasonable to estimate 100,000 such dwellings, which would make a total of approximately 250,000 houses per year. This may be taken to represent the present annual growth of population. The previous estimate of 300,000 houses per year may, therefore, be accepted as approximately representing potential demand in the near future.

Social Advantage—Homes and buildings of better construction at lower cost than the present construction, saving the Owner the first initial cost, has a social advantage.

These homes and buildings will have a greater resale value even though they stand for a hundred years.

The city dweller is safer from lightning than the country dweller, both because of the steel buildings and because of the network of electric power, light and communication wires with their lightning arresters and other grounded conductors. Of 749 fires by lightning reported in Iowa for a five year period, only 153 occurred in towns. The remaining 596 were farm dwellings and barns. Nine out of ten of these buildings burned were not protected by lightning rods. Most of the deaths from lightning, and about 600 per year is the toll for the United States and for Canada—occur in the open country.

Only a few years ago lightning was one of the most serious menaces to oil fields and tanks where petroleum and gasoline are stored, but today protective overhead systems conduct the incendiary bolts harmlessly into the ground. Perhaps it is not too much to expect that some day the forests—the most numerous victims of lightning—will be effectively protected against this greatest of all sources of forest fires.

Fire Hazard—The protection of important framing members against fire is always desirable. The same need does not necessarily apply to secondary parts. In some attempts to render residences fireproof, concrete and steel have been used to the total exclusion of wood, even for roof framing and trim. When considering the fire-resistive ability of any dwelling, the hazard should be correctly appraised, otherwise a construction is apt to be used whose advantages may be hardly commensurate with its cost.

As an indication of the attitude of fire underwriters toward fire resistive houses, the following table gives the average firm insurance rate for city dwellings in Cook County, Illinois, as of January 1931:

Type of Construction	Rate per Year Per $100 Valuation
Wood frame with wood covering	$0.40
Wood frame with brick veneer	0.20
Semi-fireproof	0.10
Wholly fireproof	0.06

Of all residence fires nearly 15 per cent start on the outside of the roof, and 70 per cent below the first floor. (Basement walls are always fireproof). Non-combustible roofing and a fire-resistive first floor construction will therefore remove approximately 85 per cent of the hazard.

If the greater part of the structure itself is non-inflammable the contents of the rooms are the only combustibles that can be consumed. In residences

the combustible contents are of limited value and the increasing use of steel furniture should make the fire risk still less.

Depreciation—Banks and loan companies never knew how poorly homes were constructed until they were compelled to foreclose on so many homes. During the depression they had found that these homes had a greater depreciation value than they had expected to find. Homes constructed with steel framing and fire-proof materials will have little or no depreciation. The banks and saving loan companies have always given us a greater appraisal value than they would on the wood constructed homes. In other words, they have granted larger loans.

Insulated Homes—Many people have sacrificed fire protection for insulation. While there are other insulating materials on the market that are fire-proof insulating materials and cost no more than what they are using today.

The reason that these fire-proof materials have not been used with wood construction is due to the fact that wood framing would not support their weight, with steel framing it is possible to use them, as the steel can be figured to carry any load.

Comparative Cost of Riveting and Welding—Estimated cost of our Wedge-weld connection, Fig. 2, and rivet construction:

Riveting Construction

Riveting shop and field work—labor....@ 35¢ per rivet	$5.60
16—3/4 Rivets @ 1 3/4¢	.28
Steel 20—@ 2 1/2¢	.50
Punched holes—28 @ 5¢	1.40
	$7.78

Welding on Wedge-Weld Construction

Labor on Welding @ $1.00 per hour	1.00
12 Rods—@ 6 1/2¢	.78
Steel—32# @ 2 1/2¢	.80
	$2.58

$5.20 saving over a rivet job. No erection, painting overhead, insurance or taxes are figured in the above. Erection cost should be about $10 a ton.

The above estimate has been based on one connection on girders and two connections on Purlin beams.

Building 43′4 × 101′4

We shall take for example a factory building of the above size of steel framing and masonry walls, live and dead load figured at 50 pound roof construction timber. The clear span of a 24″ × 9″ @ 74 pound girder beam 42′0 span, 5 bays @ 20′0 span.

On this job we would have the following steel:

6 pcs. 24″ × 9″ @ 74# 42′0 long weight	186.48#
12 pcs. C.B. Columns 6 1/2 × 8 @ 24# × 16′0	46.08#
10 pcs. Purlin Beams 10″ C.B. @ 21# × 20′0	42.00#
Total Weight	274.56#
Sheet cost per pound	2 1/2¢
	$686.40

Rivet Connection

Item	Amount
Steel	$686.40
12 pcs. Girder & Purlin Beams Connection @ 7.78	93.36
Erection cost at 1¢ per pound	274.56
	$1054.32

Wedge—Weld Connections

Item	Amount
Steel	$686.40
12 pcs. Girder & Purlin Beams connection @ 2.58	30.96
Erection cost ¾¢ per pound	205.92
	$923.28

Welding will show a saving of $131.04. We have not included any bracing angles, lintels, painting, insurance, or profit.

Chapter VIII—Arc Welding and Modern Steel Houses

By Lawrence C. Blazey and George B. Rogers

Secretary, Designers for Industry, Cleveland, Ohio, and General Contractor, Lakewood, Ohio, respectively.

Lawrence C. Blazey

Subject Matter: An attempt to remove the bad reputation and high cost of previous experimental steel fabricated houses by using a panel which has been employed for 10 years in commercial buildings. In order to reduce erection costs, the bolt and nut technique was replaced by arc welding. Flexibility and speed of arc welding methods were the principal factors in helping to reduce the erection costs.

The product discussed in this paper is a prefabricated structural panel which, for the past ten years or more, has been manufactured for use in various types of structures, such as: gasoline stations, commercial buildings, and residences.

During this time, I formulated many ideas which, about four years ago, resulted in my starting the design of steel houses.

It was only natural that I should apply these new principles to residence construction. I immediately set about to find ways and means of designing a steel house that would take advantage of the most recent engineering improvements and technical applications of various new materials and processes so as to make a steel house as interesting, artistic, and as practical as possible. We endeavored to rectify the bad reputation that previous attempts at erecting steel houses have created. To live down some of these bad experiments was a challenge to us which we were confident of overcoming. Naturally, the problem of cost was a prime requisite although, from our past experience, we had gained knowledge of erection short cuts. We were sure that there were still greater improvements that could be made.

A house is a much different problem from a commercial building, in that it must have a warm, receptive quality and, although designed modern, it could not be too extreme for the public taste. About a year ago we had completed a great many drawings for residence construction. In order to confirm our ideas and to allow us an opportunity for experimentation, I decided to erect a sample house for myself into which we could introduce anything in the way of engineered living improvements within a reasonable cost. This first house has just been completed, after almost two years' of very intensive study.

In our previous erection technique, it was necessary for the iron workers to drill holes for securing the floor, ceiling, and side wall members with sheet metal screws. It was also necessary to secure the floor and ceiling panels with bolts to the supporting angles. This took a great deal of time, and it was realized that erection costs could be reduced by the expedient of

arc welding. A single operator could follow up the erectors who merely have inserted screws for temporary support. It may be of interest to note at this point the physical characteristics of this system, referring to Figs. 2, 3 and 4.

The first requisite of a steel building is a foundation with concrete slab, around which is cast a concrete curb. On top of this curb there are anchor bolts fastening down a 3-inch x 3-inch twelve-gauge angle.

The prefabricated panels are 16 inches wide, galvanized, and given a Paint-grip finish, and are made with male and female interlocking ribs. These panels are the full height of the building. Erection is started by putting up one corner. After plumbing the corner and guying it with wires, all subsequent panels are interlocked together around the entire building. All of these panels are bolted to the base angle with hook bolts around the ribs. Likewise the top of the panels is bolted to a twelve-gauge "Z" section which makes them rigid at the top.

Fig. 1. Architect's rendering of house.

The roof or ceiling panels either 12 inches or 16 inches wide are then dropped onto these "Z" sections. The floor panels are laid in the same manner. In both cases the structural ribs are uppermost so as to receive floor or roof sheathing. In the house hereinmentioned, instead of using sheet metal screws or bolts to fasten the ceiling and floor members to the outside walls, (See Fig. 2) we have used the arc welder to tack weld the ribs together on the wall panels, and also to attach the eighteen-gauge floor and ceiling units to the supporting Z's. It was necessary, of course, to use a low current, between 60 and 80 amperes, so as not to burn holes through the eighteen-gauge metal.

This operation proved very rapid and, with one operator, it was possible in two days to tack weld the ceiling members and all the door and window lintels, as well as the sills. All of the openings were strengthened by tack weld. It was also necessary to install a 6 inch—12 pound "I" beam as a ceiling support beam. One end of this beam rested on a 4 inch pipe column which was simply welded at the bottom to an anchor plate, and bolted to the foundation. The other end of the beam was welded between the ribs of the wall panels and against the supporting "Z" section, making a solid, rigid frame which was erected in about two hours. This included the cutting of

the pipe column to the proper length with the arc. In order to erect this same structural member by any other method, it would be necessary to drill holes for gusset plates and perhaps even threaded flanges on the pipe column for bolting to the beam which would be a matter of twice the time and, unquestionably, greater expense.

The versatility of the arc welding, and its great flexibility, enabled the iron workers to meet all problems of rigidity when they were encountered on the job; it was even necessary, through an error in fabrication to recut two of the panels and weld them against the adjoining panel without having to form another rib. Reinforcing of certain weak sections over windows and doors was made very easy by the use of the arc welder which otherwise would have necessitated drilling holes and thus put all the bolts under shear through a thin eighteen-gauge metal. Arc welding permitted a greater surface attachment integral with the metal, resulting in greater structural rigidity and strength. In the application of arc welding in this house, we used a gas-driven portable welder because electric current of the amperage needed was not available. This made it a little more difficult in attempting a savings of time. Several structural problems occurred in the building which were naturals for arc welding.

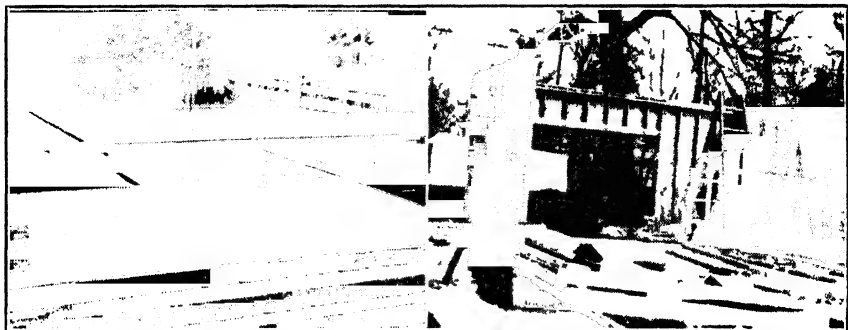



Fig. 2. (left). Roof deck clamped in position ready for tack welding. Fig. 3. (right). Beginning of erection.

One problem was the extension of the ceiling panels 3 feet out over the walls as a cantilever in which it was necessary to make the panels rigid. This was accomplished by welding small angles at right angles to the ribs, making a rigid cantilever. This would have taken a lot more time by the use of screws, and would not be as rigid.

Another problem that was adequately solved was the capping of the panels used on round corners. This channel cap had to be notched every 4 inches in order to bend around a 3½ foot radius of the corner. In applying this cap in the usual manner it would be necessary to drill a hole and put a screw in every 4 inch section. With the arc welder, we accomplished this very rapidly in about one-third the time, making a more rigid construction.

A third problem that was successfully solved by arc welding was the building up of interior steel stud partitions. In this case we used the level concrete floor of the garage and laid down a base channel and top cap as is shown in Fig. 3, and set our steel studs, spacing them 16-inches on center. This was then squared up and clamped and the arc welder used to tack all of the joints. For an 8-foot x 10-foot partition it took approximately one and

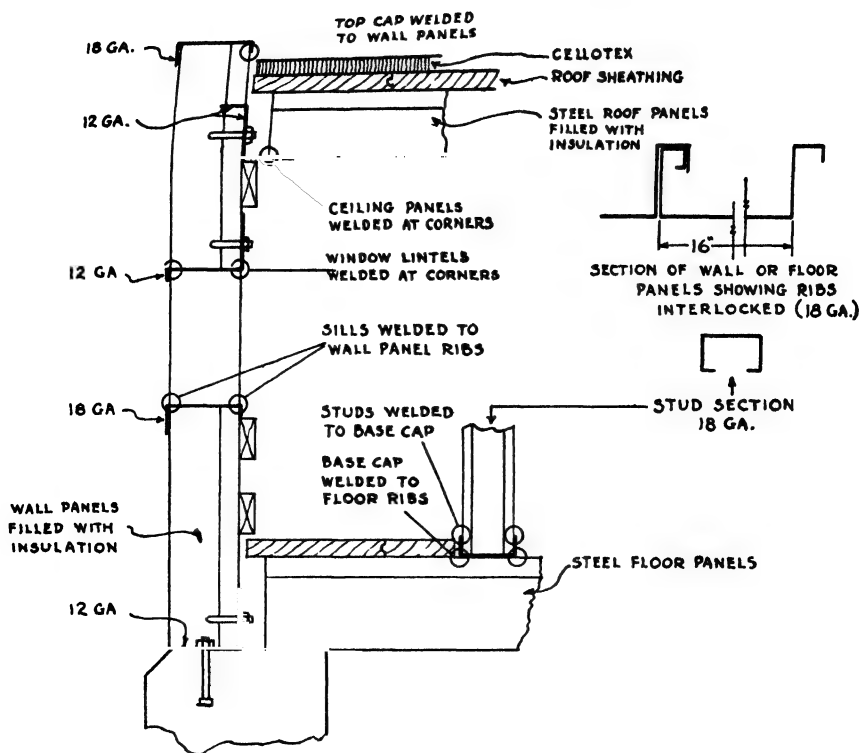



Fig. 4. Welded Joints.

one-half hours. By the old method it would be necessary to screw the members in their right places by drilling holes in every joint, which would have taken at least 75 per cent more time, and would not make as rigid a structure.

The accompanying cost sheet will give a more clear comparison of the various factors of cost which would be encountered on the average job.

Over and above the savings in cost is the more important factor of increased strength and rigidity, and additional factors enumerated on the cost sheet.

From this data on the first house, we feel sure that our erection cost could be reduced by the proper timing of the welding process with the erection, which we did not have ample opportunity to do on this particular house.

I believe this paper has demonstrated a new adaptation of arc welding to a prefabricated panel system of light gauge metal. It is our aim to further improve on our methods by the use of arc welding as soon as the present war puts us in a position to obtain the necessary steel for building more of these houses.

Cost Sheet

Welding time for first house:
1 man—20 hrs. @ \$1.87½ per hr. with gas-driven welder................\$37.50
Estimated time with motor-driven welder for same job
1 man—18 hrs. @ \$1.87½ per hr..\$33.75
Estimated time for a group of two or more houses:
1 man—16 hrs. @ \$1.87½ per hr. with motor-driven welder.............\$30.00
Estimated time for old method of drilling holes and securing by sheet metal screws and bolts in Summer weather:
2 men—24 hrs. @ \$1.87½ per hr..\$45.00
Estimated time—old method—in winter weather with gloves:
2 men—28 hrs. @ \$1.87½ per hr..\$52.50
Estimated time for drilling and screwing one sheet metal screw.......................................2 minutes
Estimated time for striking arc and tack welding...1 minute
50 per cent reduction in time per joint

Additional advantages not gained by old method of sheet metal screws and bolts:

1. Extra rigidity
2. More surface contact between welds.
3. Inaccessible places easy to get at with arc welder; more convenience, as only one man needs to do welding.
4. Faster erection as crew does not have to stop and wait for the process of putting in screws to temporarily support panels.

Chapter IX—Welded Caissons for Naval Dry Docks

By Captain C. A. Trexel (CEC) USN and A. Amirikian,
Director of Planning and Design and Principal Engineer, respectively, Bureau of Yards and Docks, Navy Department, Washington, D. C.

Captain C. A. Trexel

Subject Matter: Former methods of calculation and design are discussed and the new elastic slab method is presented which is more applicable to welded construction. Designs were prepared for two large caissons of riveted construction. It was then decided to prepare alternate designs of all welded construction. These were submitted for bids. Eight contractors participated in the bidding. The low bid for the two caissons for the welded design was $108,030 less than that for the riveted design, amounting to 25% in cost. As a result, the Navy Department has let a number of other contracts for similar welded structures.
Net savings for caissons built and under contract $1,652,000. Savings on projected construction in the immediate future $3,540,000 Savings in weight (projects built) 4200 tons and (caissons projected) 9000 tons

A. Amirikian

A dry dock or graving dock is generally described as a water basin with a removable gate, which provides a dry berth for maintaining, repairing or building ships. Since the early days of navigation, dry docks have played a prominent part in the progress of shipbuilding. Because of the nature of the services which they render, the history of their growth and development is closely allied with that of ships. Paralleling the development of the merchant fleet, the crude basin of the wooden-ship era has gradually emerged into the present-day dry dock of immense dimensions and streamlined appearance, (see Fig. 1), as a worthy counterpart of the modern ocean-liner and a contributor to its successful operation.

Dry docks are likewise of primary importance to the maintenance and operation of the naval fleet. While some service to smaller craft is rendered by marine railways, the repairs to major vessels must necessarily be carried out in floating or graving dry docks. The importance of such shore facilities, particularly in time of war, needs no elaboration. Without them, ships would, in time, become immobile and useless because of fouling of bottoms, damaged propellers or rudders, and many a battle damaged ship would be lost.

Dry Dock Closures—The entrance closure is an integral part of a basin dry dock. The two factors governing its selection and design are mobility and strength. The former is required for clearing the entrance and thus enabling the ships to float in and out of the dock. The latter is an obvious requirement for withstanding the external water pressure when the dock is pumped out. Mobility may be provided by any of three types of closures: hinged miter gates, similar to canal lock gates; sliding or rolling caissons; or

removable floating caissons. Gates are installed in many European dry docks. The sliding type of caisson, which is drawn into a recess at the dock entrance to permit the entrance or removal of a ship, is a favorite at English and British colonial dockyards. In American practice, the floating caisson is the most commonly used form of dry dock closure.

Floating Caissons—As the derivation of the word would indicate, a caisson is essentially a box. This box is composed of a system of interior framing and an enveloping skin plating. The interior framing, in turn, consists mainly of a series of trusses or girders, spanning longitudinally and transversely. The skin plating, which is of water-tight construction, is supported by a set of girts or stringers forming the secondary framing.

The cross-sectional outline of a caisson is determined from the conditions of stability and minimum draft in floatation and the necessary strength when in the seat and subjected to the unbalanced water pressures. As in the case of ships, the cross-sectional outline has undergone considerable change. In the early days of naval construction, when labor was inexpensive, and the time element not so pressing, the general tendency was to choose curved outlines of what would now be considered doubtful efficiency. Some of these outlines are shown in (a), (b), (c) and (d) of Fig. 2, representing, in that order, the bulb, ship, hydrometer and barrel-shape types of caissons formerly used. In (e) we have the modern, simple, yet efficient, box-type framing outline, used by the Bureau of Yards and Docks, Navy Department since 1940. The latter follows structural framing practice rather than the more costly orthodox ship construction used in former caissons.

In the earlier days of shipbuilding, when the dock closures were of rather small dimensions, caissons or gates were built exclusively of timber. Later, with the advent of the iron ship, iron was utilized to a great extent. In the present era of naval construction, caisson material consists mainly of steel.

Analysis of Caissons—In the earlier forms of framing arrangement, the design of the caisson involved no complex problems. The panels of timber were analyzed as simple beams spanning the two walls of the dry dock, and each carrying the hydrostatic load within its boundary. According to this

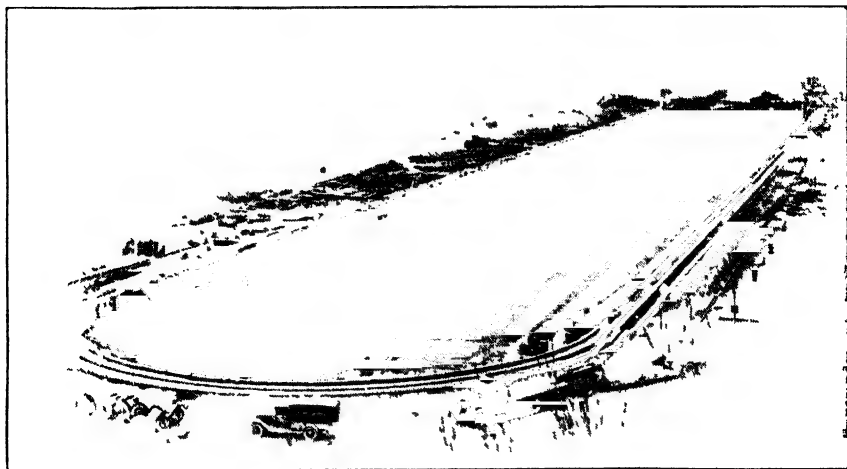



Fig. 1. View of a modern drydock, with caisson in the background.

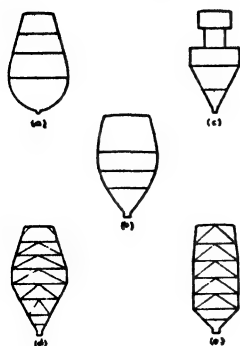
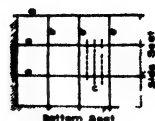
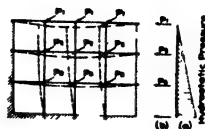
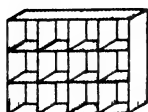



Fig. 2. Typical cross-sectional outlines of drydock caissons, shaped as: (a) bulb; (b) ship; (c) hydro-meter; (d) barrel; and (e) box. Fig. 3. Plan of caisson framing: (a) horizontal girder; (b) vertical frame; and (c) secondary framing. Fig. 4. Deformation of grid under concentrated panel loads. (a) Distributed water pressures; (b) Resultant panel loads. Fig. 5. Main framing arrangement of caisson, with shell plating removed. Fig. 6. Concept of grid framing as applied to a box.

arrangement, the entire load was transmitted to the side walls of the dry dock, and the pressure distribution was assumed to vary from zero at the top of the side wall seats to a maximum at the bottom.

With the introduction of the so-called grid-system of framing, in which the horizontal girders were supplemented by a similar series of vertical frames, the analysis became statically indeterminate. The function of the vertical framing was two-fold: (a) to transfer a part of the water pressure from the heavily-loaded lower girders to the more lightly-loaded upper girders and (b), to assist the horizontal girders by transmitting a part of the hydrostatic load to the bottom seat.

A simplified concept of the main framing is shown in Figs. 3 to 5. The outline of the main framing or grid is indicated in Fig. 3; Fig. 4 is an exaggerated view of the deflections of the grid under concentrated panel loads; and Fig. 5 is an isometric presentation of the grid or cellular box, consisting of the interior framing with the shell plating removed.

The hydrostatic load acting on the box is transmitted to the three supports, first by local bending of the various members of the secondary framing and then by bending of the main framing as a whole. For the first part, the problem is rather simple. The shell plating, spanning over the secondary supporting frame, acts as a continuous member to transmit the distributed loading to the supporting stringers. The latter, in turn, also bending as continuous beams, transfer the water pressure to chords of the main framing in the form of a series of concentrated loads. The chords, likewise bending locally, carry the intermediate concentrated loads to the main panel points located at the intersections of the vertical and horizontal frames, thus finally resulting in a loading system as shown in Fig. 4. The problem of the bend-

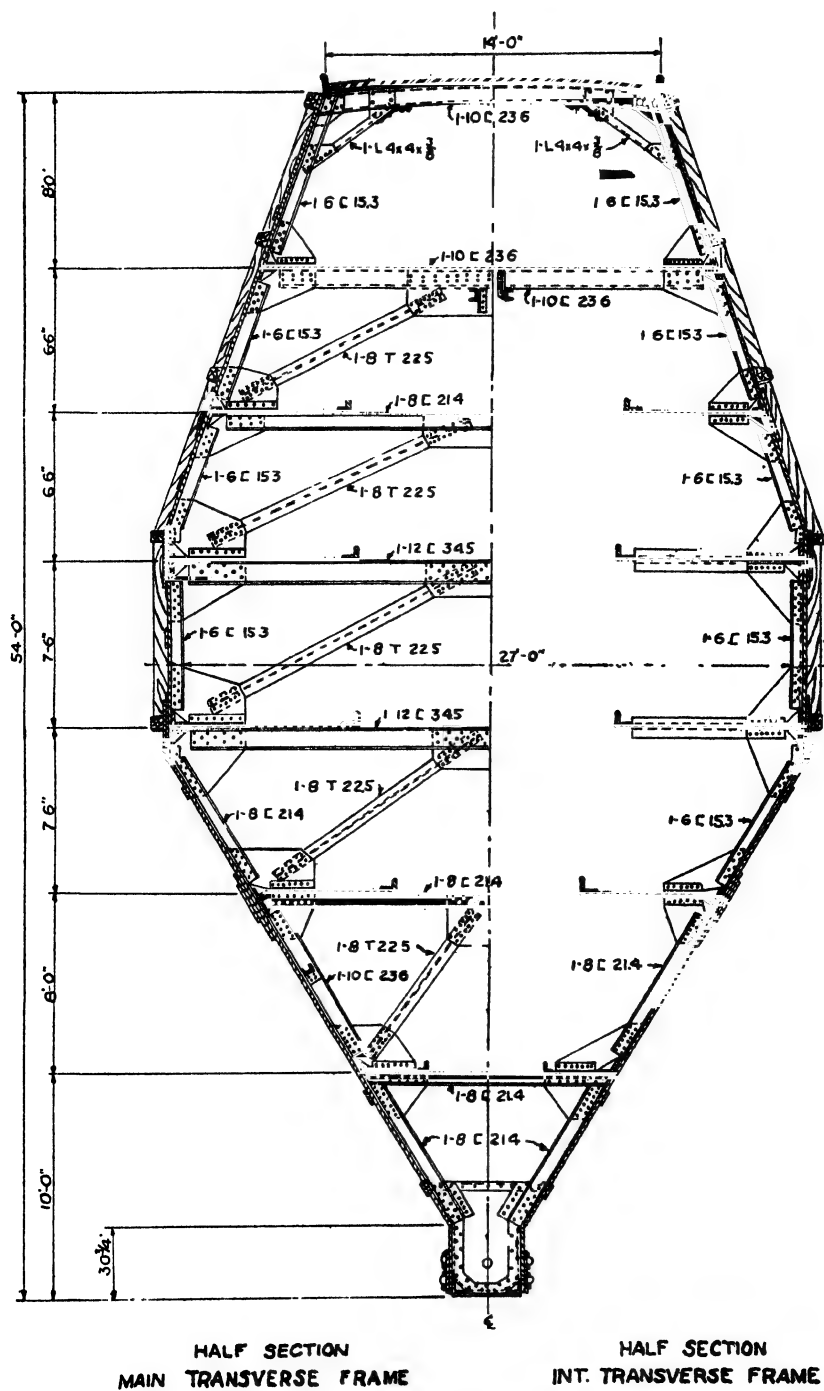



Fig. 7. Cross-section of a conventionally-designed riveted caisson, showing typical transverse framing.

ing of the box as a unit under this loading, however, is quite involved, since the equations of static equilibrium alone are not sufficient for determining the two components of each panel load which must be transmitted to the side and bottom seats through the respective framing.

Former Methods of Analysis—Since early days of design, many attempts have been made to simplify the analysis. Some of these efforts consisted of rendering the system statically determinate by various arbitrary assumptions. Others were predicated on dividing the loading between the two directions of bending through supplementary consideration of probable or assumed deflections; and still others were based on the principal of "least work". A brief description of the several methods follows:

Illustrative of the first group, and perhaps the earliest method of analysis, is the so-called method of one-way bending, in which it is assumed that the loading is carried entirely by the horizontal girders and that the vertical frames act merely as bracing members. Obviously, the unsatisfactory basis of analysis and the waste of material resulting from such a design needs no elaboration.

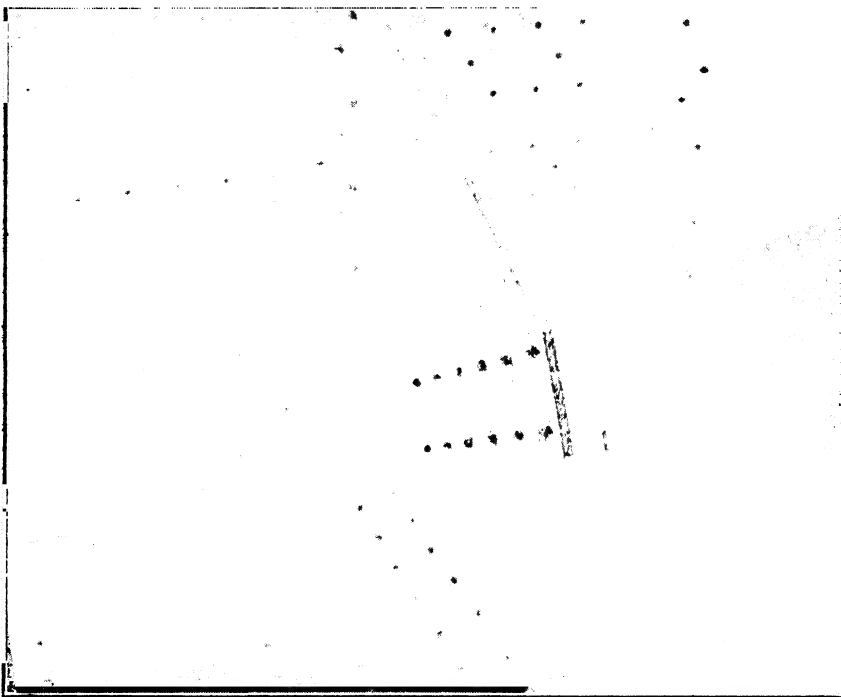



Fig. 8. Close-up view of typical joint detail in a riveted caisson framing.

The method of assumed deflections had been used for caissons designed up to 1919, which were the last ones built for twenty years, thereafter. While some consideration is given in this method to the role of the vertical frames, at best, it is a crude approximation of the grid theory. To determine the share of loading for each girder, first the form of the probable deflection curve is assumed at the vertical center-line of the framing. Then, by trial and error, the loading is adjusted and the flange material for each girder is

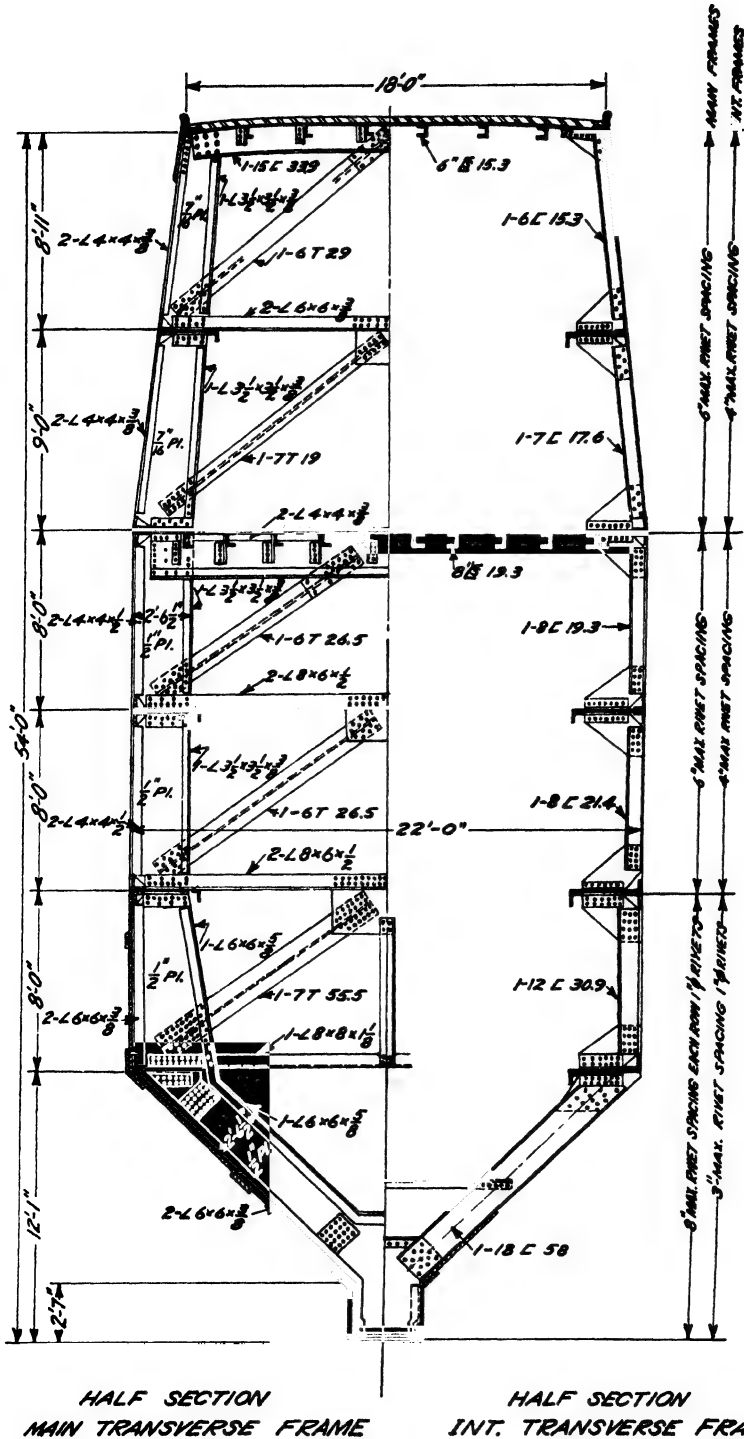



Fig. 9. Cross-section and typical framing arrangement of a riveted caisson, designed by the elastic slab theory.

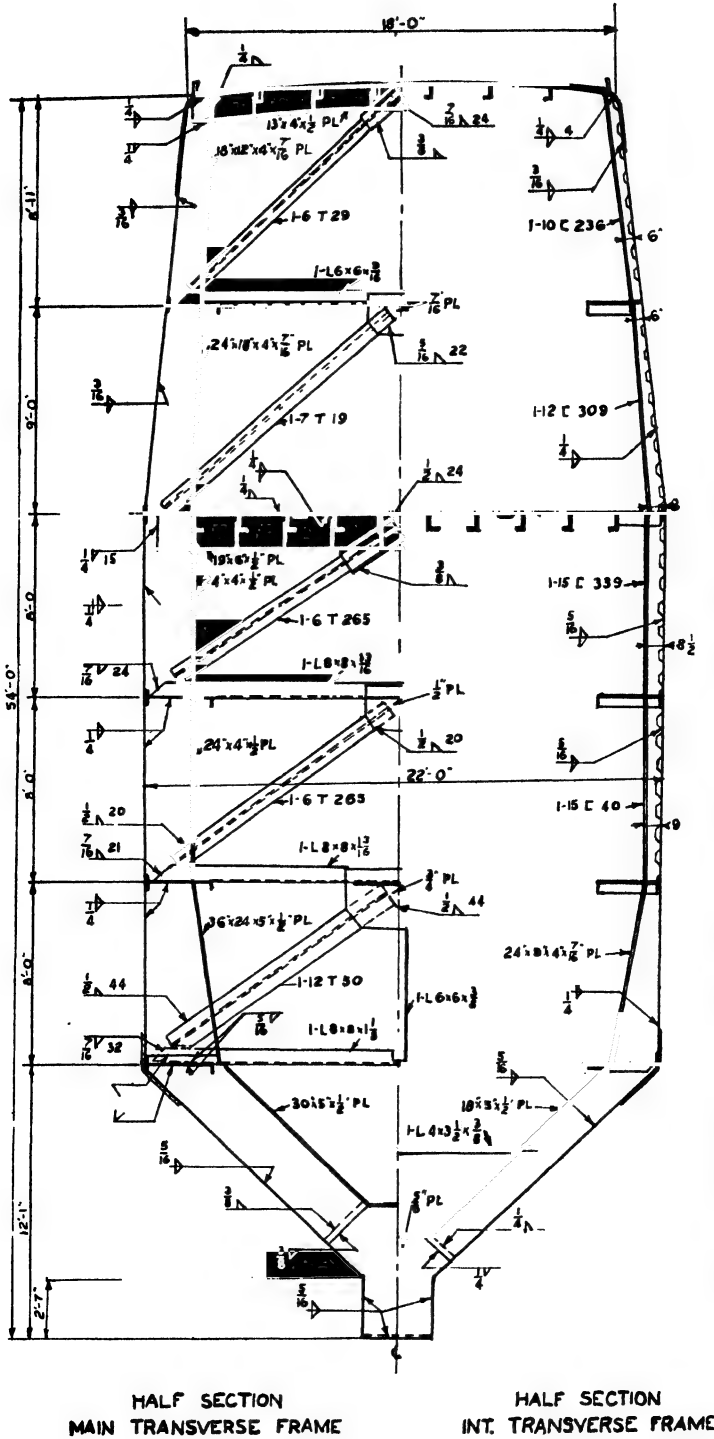



Fig. 10. Cross-section and typical framing arrangement of a welded caisson, designed by the elastic slab theory.

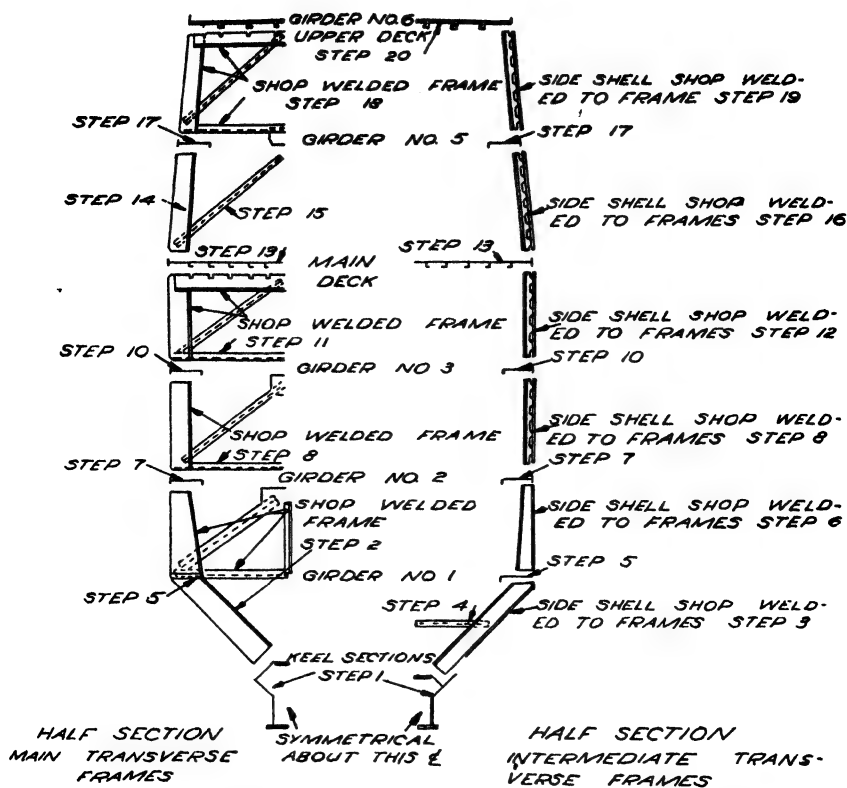



Fig. 11. Erection procedure of shop sub-assemblies of welded caisson.

proportioned to conform to the respective maximum deflection on the assumed curve. While the equilibrium conditions are satisfied in the solution, the method is defective in that the same panel loads are used for all vertical frames, regardless of their location with respect to the supports. As a result, the distribution of loading between the two directions of framing does not represent the true conditions nor the one requiring the least sections in bending.

In the method of "least work", the framing system is assumed as a grid, and the panel loads carried in one of the two directions are considered redundant forces and their intensities determined from the equations of "least work".

Concept of Former Method—In the older methods of design, the strength

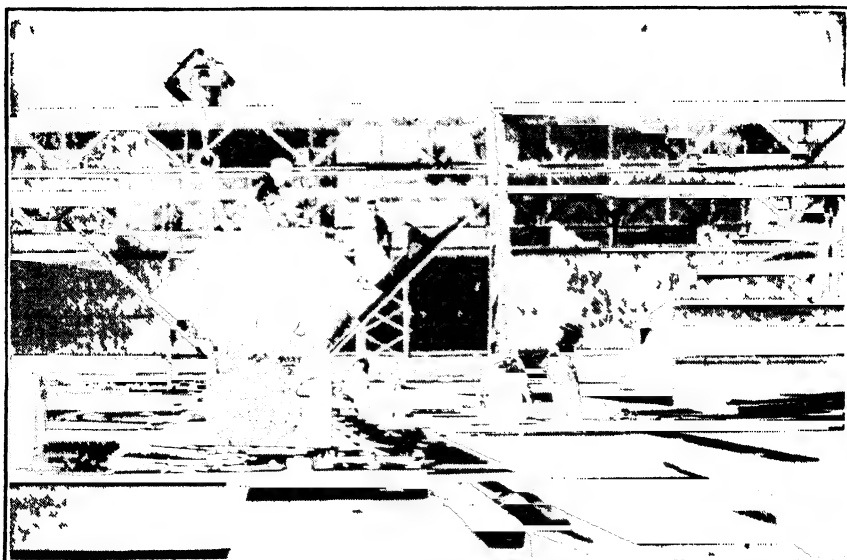



Fig. 12. Shop welded keel section of caisson.

of the shell or skin plating is only partially utilized in the bending of the caisson as a whole, the assumed contribution being limited to the furnishing a certain amount of flange material for the main frames In effect, such a concept is analogous to considering the caisson as a box having its top and bottom perforated with rectangular openings Fig 6, showing the plan view of the plate panel, illustrates this concept Here, the unshaded area of the diagram indicates the effective part of the plating, consisting of a series of vertical and horizontal strips Each strip represents the effective flange plating acting in conjunction with the girder or frame at the respective location, the width being governed by the plate thickness

Concept of New Method—The imaginary holes in the plating had been introduced with a view to divorcing the direct interdependency of bending in the two directions, and thus simplifying the analysis Obviously, because of the solid skin plating, no bending of the nature of an open grid framing can take place. If it be assumed that the plating is adequately anchored or connected to the interior framing, when the box is bent, the original plane flanges are forced into dished-in or spherical contours, conforming to the bending curvatures in the two directions As a result, the flange plating is not only subjected to bending fiber stresses but to twisting strains as well, the latter attaining their maximum intensities at the four corners where the bending curves in the two directions merge into a single common curvature. Compared to the two-way bending of a grid, the twisting resistance of the plating has the effect of equalizing and relieving the bending stress of the framing, thereby resulting in a more satisfactory and economical design

Analysis of Caisson as a Cellular Elastic Slab—The bending phenomenon just explained is that of an elastic slab As stated above, if the skin plating and the various members of the framing are securely connected together to form a rigid unit, then the caisson may be considered as an elastic slab in which, in lieu of a solid cross-section, the material is concentrated in the flanges and in a series of web frames to form a cellular box.

Design of Caissons—In the fall of 1939, construction was nearing completion of a caisson for dry dock A at Navy Yard X. The caisson, the largest closure in span and depth to that date, had, for lack of time to prepare a radically new design, been designed in accordance with the Bureau's former conventional method of analysis discussed above, and had riveted connections. Fig. 7 illustrates the cross-sectional outline and some details of framing. As will be noted, it is of the barrel-shape type, with a maximum beam of 27 feet and a depth of 54 feet. The maximum length at the top is 150 feet. The details follow the general pattern of accepted standards of riveted construction, as may be noted in the close-up view of a typical joint detail shown in Fig. 8. The total weight of the caisson, exclusive of the concrete ballast, was 2,256,700 lbs.; the cost, $389,650, and it was completed in 18 months.

New Caisson Design—At the time of construction of caisson A, a very large expansion program of docking facilities was just getting underway. First on the list were two new dry docks having entrance sections identical with that of dry dock A, one of them located at Navy Yard X and the other at a distant Yard Y. Under normal conditions, the logical procedure would have been to duplicate the former design for which plans were available. However, having conducted considerable research and investigation in the field of elastic slab analysis with a view to possible application to the design of caissons, and having developed a simplified computation routine from the obviously involved theory, the Bureau decided to prepare a new design based on the elastic slab concept.

Riveted Framing—The new analysis being a radical departure from conventional methods formerly used, it was deemed prudent in the first design to confine pioneering to the analysis only, and to design the new caisson in riveted construction.

In preparing the new design, the available data of the caisson for dry dock A (last conventional design) were utilized both as a guide as well as a basis of comparison. Fig. 9 shows the main features of the new framing. As will be noted, the new cross-sectional outline, in the form of a slenderized box, presents a striking contrast to the bulky, barrel-shaped outline of the former design. Other changes consisted of revised girder and frame spacings,

Fig. 13. View of partially assembled caisson, showing parts of main transverse framing.

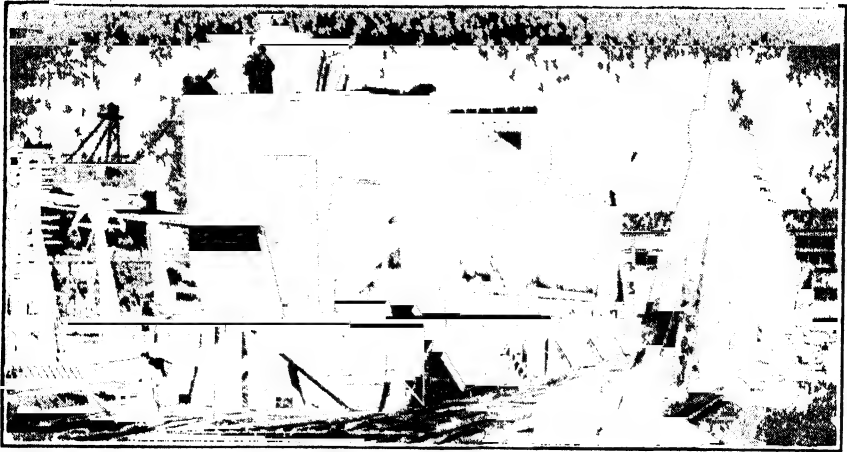



Fig. 14. View of partially assembled caisson, showing parts of stem and end framing.

elimination of double plates from girder flanges and redistribution of material throughout the framing

The estimated weight of the caisson, exclusive of concrete ballast, was 1,950,000 pounds, representing a reduction of 306,700 pounds from the weight of the former design

Welded Framing—While the design drawings for the new riveted caisson framing were in course of preparation, the question was raised whether the original decision to use riveted construction ought not to be reconsidered in view of the number of new caissons involved and the possible large economies which might be achieved by the use of welding Up to that time the Bureau had not used welding in the fabrication of its floating caissons As support for the adoption of welding, it was argued that, since the elastic cellular slab concept was predicated on rigidity of connections, there was more justification for using the new analysis in welded construction of proven rigidity than in riveted construction of somewhat dubious rigidity As a compromise, and to obtain a direct comparison, it was agreed to prepare an alternate design of welded framing, and to submit both schemes of construction for bids

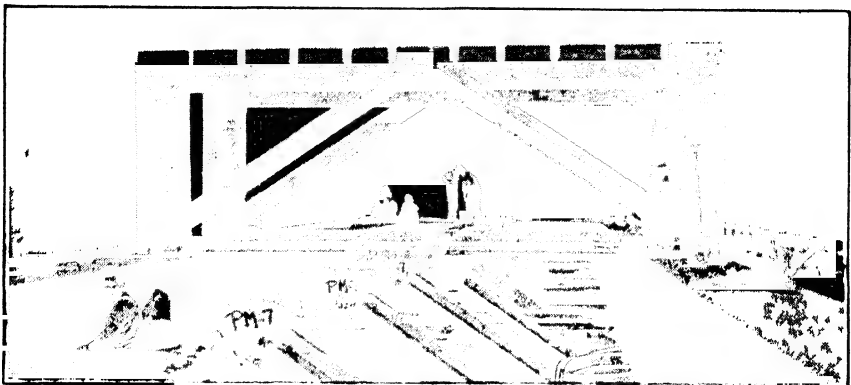



Fig. 15. Top view of partially assembled caisson, showing some details of the interior framing.

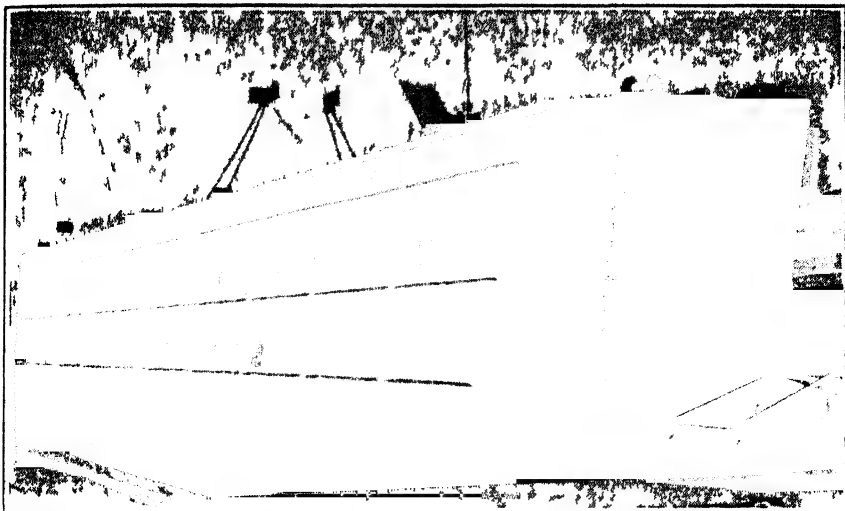



Fig. 16. First all-welded caisson complete and afloat. Beam 22 ft., depth 54 ft., length 150 ft.

Details of Welded Design—The success of any welded design depends greatly on its planning and development as a new and entirely distinct structure, free from the influence of the details of the riveted design which it replaces With this in mind, in preparing the details of the alternate welded design, the parts for each member of girder and frame were carefully selected to provide not only the lightest weight and maximum strength but also the most advantageous section for welding To this end, generous use was made of serrated channel sections, cold formed angle sections and wide-flange tee sections Fig 10 illustrates the basic details of construction It is to be noted that all horizontal girders have a combination tee-angle flange section The small tees, while not needed for strength, were added to provide a landing and backing strip for welding of the horizontal seams of the shell plating The connections were further improved by substituting two separate fillet welds in lieu of the customary butt weld, thus allowing a tolerance gap between the edges of two adjoining shell strakes, at the same time reducing the possibility of locked-up stresses which might result from long butt seams The employment of serrated sections results in a saving in channel material and the use of a minimum amount of welding with sealed connections at the lines of contact with the plating The flanged sections of the girder and frame chords furnish the required stiffness and stability in flexure, obviating the need of welded legs

Working Stresses—In determining the amount of welding at the various points, the following unit stresses were used:

Fillet welds	13,560 psi
Butt welds.	
Tension	15,600 psi
Compression	18,000 psi
Shear	12,000 psi

Other details and welding requirements were in accordance with Bureau of Yards and Docks welding Specs 12yb-Supplement No 1a and 22yb.

The estimated weight of the steel and fittings of the caisson was 1,505,000

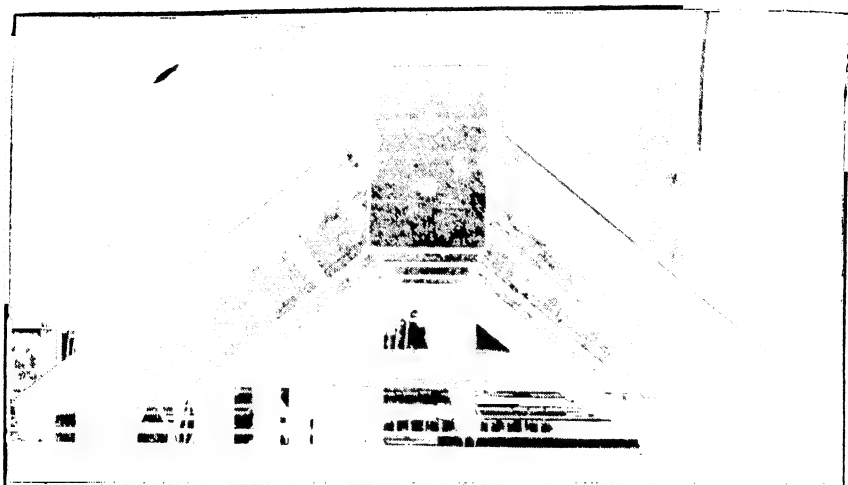



Fig. 17. Section of keel of caisson, sub-assembled in the shop.

pounds, or 445,000 pounds less than the weight of the new riveted design, and, 751,700 pounds less than that of the old riveted design.

Comparative Caisson Costs– Drawings for the two designs were completed early in 1940, and submitted for bids. The bids were asked for each caisson separately as well as for the two units together. Eight contractors participated in the bidding, the list including the builder of the Bureau's last riveted design. Of the eight bidders, four quoted prices for the welded design only, three gave incomplete bids for the riveted design and one submitted bids for both designs. The lowest figures were as follows:

(a) Welded design:

One caisson for Navy Yard X	$266,703
One caisson for Navy Yard Y	276,203
Both caissons	522,570

(b) Riveted Design:

One caisson for Navy Yard X	$355,540
One caisson for Navy Yard Y	366,740
Both caissons	630,600

It is particularly interesting to note that the low figures of the welded group were those of a builder who had actually fabricated the Bureau's last riveted caisson mentioned above, the work being sublet to him by the successful bidder of that project; and, significantly, he had submitted no bids for the riveted group at this time.

Fabrication and Construction—The contracts for the two caissons were awarded to the low bidder of the welded design, and thus the work was being started on the first all-welded caisson construction. The caisson being a floating structure, the event marked also the beginning of a large-scale utilization of welding in such structures under the cognizance of the Bureau.

By the terms of the specification, the contractor was required to submit the proposed method and order of assembly and sequence of welding for approval before proceeding with the actual fabrication. The submitted procedure in outline form is shown in Fig. 11. The erection being confined to the vertical position of the caisson, the proposed method differed but little from the one

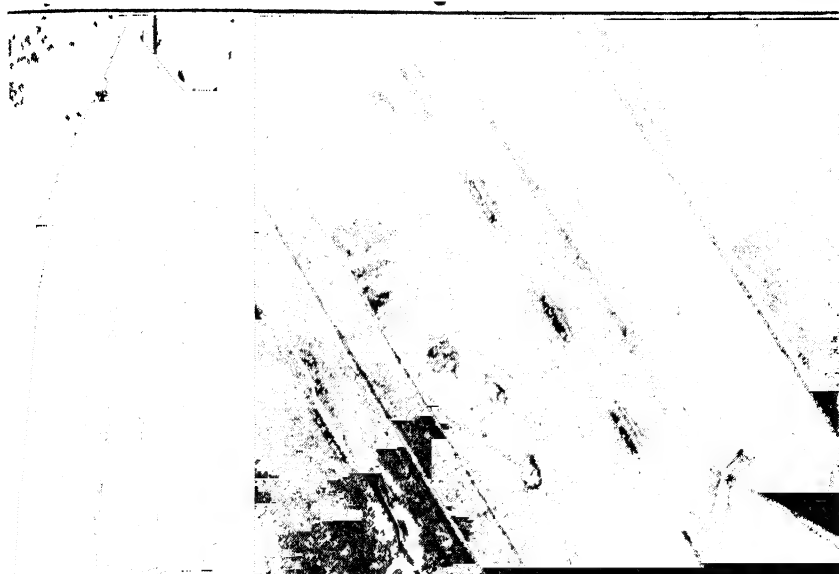



Fig. 18. (left). Stem and end framing section of caisson being lowered in position for erection. Weight of the shop-welded sub-assembly unit about 15 tons. Fig. 19, (right). Close-up interior view of caisson, showing joint details of main and intermediate frames at the knuckle.

envisaged in the design. Another clause in the specification gave the contractor the option to use, upon approval by the Bureau, welding details other than those shown on the design drawings. No important changes were, however, proposed to alter the original details.

Fig. 12 shows the placing of the first keel section of the first caisson at the assembly site. Fig. 13 shows the assembled keel section and the lower parts of the main transverse framing. Fig. 14 is a view of the partially assembled end framing, consisting of a part of the stem section, the breast hooks, the water-tight bulkhead and the shell plating up to the elevation of Girder No. 3. In the foreground, a sub-assembled plate panel with serrated-channel stiffeners can be seen. Fig. 15 is a top view of the partially assembled caisson, showing some details of the interior framing. Fig. 16 shows the completed caisson afloat.

Additional Welded Caissons—As a result of the favorable bids received for welded caissons, a policy was adopted by the Bureau to exclude riveted designs from further consideration and to use welded construction in all subsequent work. Accordingly, on June 1, 1940, contracts were let for the construction of two additional caissons of smaller dimensions, involving 430 tons of steel by welded design. Figs. 17 to 22 illustrate some interesting features of construction of this second group. In the order of work progress, Fig. 17 shows a keel section, subassembled in the shop, ready for shipment to the erection site; Fig. 18 shows a section of the stem and end framing, a 15-ton shop-welded sub-assembly being lowered in position for erection. Fig. 19 shows the joint details of main and intermediate frames at the knuckle. (These simple clean-cut welded details may be compared with the corresponding riveted details shown in Fig. 8.) Fig. 20 is a view parallel to the keel below the knuckle, showing a battery of arc-welding machines, ready for welding the

sub-assembled units. Fig. 21 is a view of the caisson at an advanced stage of erection, illustrating the adaptability of welding to high-speed production at the assembly site, in this case showing simultaneous welding by 16 welders (4 inside and 12 outside).

In addition to these four caissons, during the period of July 1940 to January 1942, designs were prepared and contracts were awarded for additional caissons of varying sizes. The total amount of steel required for these new projects is in the neighborhood of 12,000 tons. Some of these caissons have already been completed and are now in successful operation; others are at various stages of completion at fabricating shops or at the assembly sites.

Advantages of Welding

Savings in Cost—One of the first considerations in any project is obviously the cost. The contract prices of the last conventionally designed riveted caisson and the new welded design for the dry docks at Navy Yard X described above, indicate a maximum cost differential of $122,947 for one caisson. Deducting from this sum $34,110 as a saving due to the improved method of analysis, the balance of $88,837 represents the minimum or net saving resulting from use of welding, which is a 25 per cent saving, and is equivalent to approximately $118 per ton of steel used in the welded design. On the basis of the latter figure, the net savings realized from caissons built or presently under contract, involving a total of 14,000 tons of steel, is $1,652,000; and the anticipated savings from projected construction in the immediate future, involving some 30,000 tons of steel, is $3,540,000.

Savings in Weight—As stated in a preceding paragraph, the weight of steel in the first welded caisson was 751,700 pounds less than the former riveted design. Of this total reduction, 306,700 pounds was due to the application of the elastic slab theory to the design and the balance of 445,000

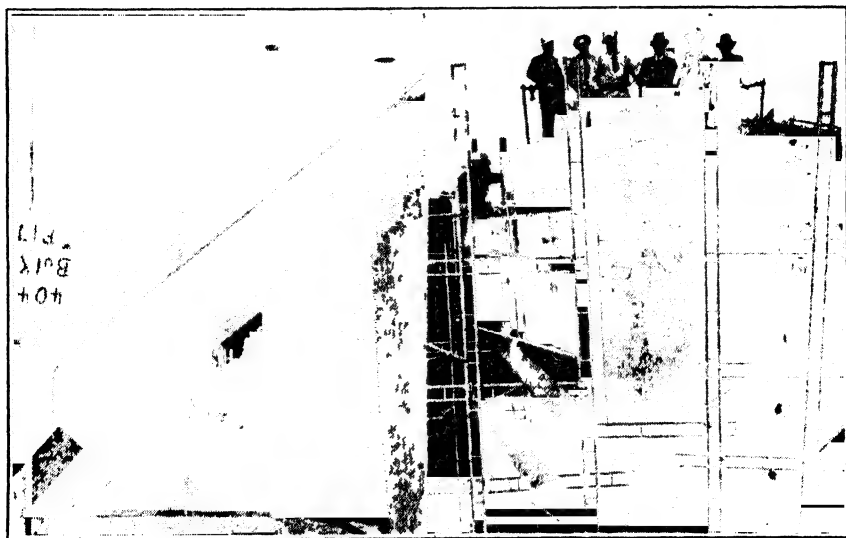



Fig. 20, (left). View of assembled keel of caisson showing a battery of arc welding machines used in the erection of the framing. Fig. 21, (right). End view of the partially completed caisson, showing a group of 12 operators welding three strakes of shell plating, while 4 others are at work inside welding butts at two decks.

pounds represented the net minimum saving as a result of welding. Expressed in percentages, the reductions from the old and new riveted designs are respectively 33.3 per cent and 22.8 per cent, or approximately 0.5 and 0.3 pound per one pound of metal used in the welded caisson. On the basis of the latter figure, the total savings in weight for the caissons under the present construction program is about 4,200 tons, and that for the projected construction will approximate 9,000 tons.

Saving in Time of Construction—The time of completion and delivery of the last riveted caisson was approximately 18 months, whereas of the first group of the two welded caissons the first was contracted for and delivered at Navy Yard Y in about 12 months and the second one at Navy Yard X three months later. With the ever-improving technique of welding, shop fabrication is steadily approaching the pace of high production, thus resulting in further shortening of the completion periods. This important time-saving element is clearly reflected in recent contracts for welded caissons.

Savings in Maintenance Cost—In floating structures, welded construction possesses a distinct advantage over that of riveted construction. Caulking is used extensively in the latter to provide the required water-tightness. Caulking is not only costly but often ineffective, resulting in leakage and corrosion and consequent overhaul and repairs. Welded construction if properly done, automatically provides watertight seams, and thus assures appreciable savings in the cost of maintenance of the caisson.

Added Strength and Stability—Paradoxical as it may seem, the welded caisson of reduced weight is stronger than the heavier riveted design which it replaces This is due to the fact that rigidity of connections in the former helps to develop fully the various sections of the framing, at the same time utilizing, in the form of added-strength, a part of the savings from the eliminated dead-weight connectors as well as from substituted sections of high stress efficiency. In addition, the lighter welded caisson requires relatively shallower draft in floatation and has greater stability.

Incidental Benefit—The advantages enumerated above do not include a still greater benefit which cannot be measured by the standards of a world at peace. A part of the savings in steel tonnage was reused in a different form in some of the caissons, as armor plating, to provide protection against bombing. Another part made it possible to construct some of the spare caissons now in the process of fabrication, and still another part went into the construction of ships and other combat weapons. These transformed savings constitute the real contribution which welding, as applied to naval dry dock caissons, has made to the violent effort which mankind is now making to insure a more secure and free way of living.

Chapter X—Welded Steel Bents for Subways

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Subject Matter: At present no welding is used on subway bents except to connect cap and base plates to columns. The writer, a structural engineer with 34 years of experience in subway design, points out the substantial savings that will accrue from even a conservative use of welding on the portions of the subway system that remain to be constructed. He offers designs for welded details to meet special subway conditions. Among them is a design for a flexible connection of beam to column.

This paper relates to structural steel work for subways, especially those of New York City. Up to the present time no welding has been used in New York for subway steel except for the connection of cap and base plates to rolled columns, and in a very few instances for the attachment of stiffeners to rolled sections. Beyond the exceptions noted, welding is not permitted for subways in New York. They are built by the Board of Transportation by the City of New York. The writer is associated with the design of subways as a structural engineer with the Board. He has been in this job on the design of subways for thirty-four years.

The preferred type of subway construction in New York consists of steel bents spaced about five feet in the direction of the length of the subway. Small concrete arches extend between the bents.

There are special conditions involved in the stresses to which steel in a bent is subject that make the welding together of its component parts more than a matter of merely substituting welding for riveting. And if these special conditions are met, an occasional defective weld would not endanger the safety of the structure any more than an occasional defective rivet would in a riveted structure.

It will be shown that with a proper design, the steel for at least two-thirds of the length of future subways can be arc welded with safety and at a saving of about $100,000 per mile of four-track subway and about $50,000 per mile of two-track subway. There are about fifty miles of new subways in the offing for New York for the first fifteen years after the war, and after that, in the course of twenty-five years more, another one hundred miles.

Design Applies to Bents Between Stations—For the conditions obtaining in New York, the open cut method of constructing the subways is most suitable. Only under exceptional conditions are subways constructed there

FIGURE 1
TYPICAL SECTION OF SUBWAY BETWEEN STATIONS
INVERT ABOVE WATER

FIGURE 2
TYPICAL SECTION OF SUBWAY BETWEEN STATIONS
INVERT BELOW WATER

FIGURE 3
TYPICAL SECTION OF DOUBLE DECK SUBWAY
PROPOSED CONNECTION FROM 60TH ST TUNNELS
TO QUEENS BOULEVARD LINE

WELDED STEEL BENTS
FOR SUBWAYS

FIGURE 4
PLAN OF TYPICAL 4 TRACK SUBWAY
(ONLY A FEW TIE RODS ARE SHOWN)

FIGURE 5
LONGITUDINAL SECTION

WELDED STEEL BENTS
FOR SUBWAYS

Figs. 1, 2 and 3, (left). Figs. 4 and 5, (right).

by other methods, such as by tunneling when in deep rock or in under-river crossings.

In open cut construction, Figs. 1, 2, 3, 3A, 3B and 3D, a trench is dug in the street and sheeted, the trench being of a width suitable to contain the subway and of a depth below the street surface sufficient to accommodate the bottom of the subway. The subway is then constructed in the trench, after which earth is placed on top of the subway to fill up the space between the top of the subway and the pavement; finally the pavement is restored on top of the fill. The sheeting at the sides of the cut is plainly seen in Figs. 3A and 3B. In Fig. 3C no sheeting is used because the subway is being built through open territory instead of an existing street where street traffic must be maintained.

The subway itself consists of a succession of steel bents, each bent extending in a line across the width of the subway, Figs. 3A, 3B, 3C, 3D, 4, 5 and 6. The bents are usually spaced five feet center to center along the length of the subway. Concrete arches extend between successive bents, Fig. 5, embedding the steel of the bents between them. Each bent consists of a row of roof beams placed end to end, with columns located under the beams at their junctions and at the outer ends of the outer beams. This framing applies to the subway between stations. At stations, which comprise only about 20% of the length of the subway, the framing is different, because wide spaces must be left longitudinally between the columns for the unobstructed movement of passengers; to accomplish this, longitudinal girders or headers are required into which the transverse roof beams frame.

The welded design described in this paper applies to open cut subways of the steel bent type but only for the stretches of the subway between stations, which stretches as noted before, comprise two-thirds of the subway. The welding of the structure at stations presents a different problem which is not treated herein.

Loads and Stresses of a Bent—The conditions of stress and strain in the members of a subway bent and the requirements established as the result of over forty years of subway building are somewhat different from those found in other structures, notably buildings. One of the important conditions not usually met with in the other structures is that not only must the bent support the downward load on top of the subway roof, but it must also resist the lateral or earth pressure against the side walls of the subway and often, in addition, there is water pressure, should the subway extend below the level of water in the ground, Figs. 2, 3, 3B, 21 and 22. Other conditions peculiar to subway construction and practice will become apparent later on in the paper.

The type of bent, Figs. 3A and 6-9, actually used in the Independent System of subways, the latest to be built, will be used as the basis of comparison between a riveted bent and the welded bent. The details shown were taken from the American Bridge Company's shop drawings for the Fulton Street Line in Brooklyn. The photo is of the subway on Queens Boulevard. The bent of Fig. 6 has been designed for a cover of 14½ feet. In subway parlance "cover" means the distance between the street surface and the underside of the roof beams, as seen in Fig. 1. Fourteen and one-half feet has been selected because it is the average cover on the Independent System for the type of construction being considered. It is fair to assume that the same average cover will obtain on future subways.

The roof load in subway practice is taken as 600 pounds per square foot live load on the street surface plus a load of 100 pounds per cubic foot of cover to the underside of the roof beams. In the present instance, remembering the cover is 14.5 feet, there is a total roof load per square foot of 600 + 1450 = 2050 pounds. See Fig. 6. The bents being spaced 5 ft. on centers, Figs. 4 and 5, each roof beam takes 10,250 pounds per lineal foot. The fiber stress in bending used for subway steel is 20,000 pounds per square inch, but when encased in concrete arches, Fig. 5, 25,000 pounds is used. This is based on the assumption that the concrete will help take up some of the compression in the upper flanges of the beams in a sort of hybrid reinforced concrete action. In accordance with this, the roof beams shown in Fig. 6 are required.

For the sidewalls of the subway above water, as in Fig. 1, the maximum bending moment on the sidewall columns due to lateral earth pressure is 1,150,000 inch-pounds the practice being to neglect the effect of the live load from the street surface. It should be remembered that the columns are spaced 5 feet on centers along the length of the subway and therefore take the lateral pressure against 5 feet of the wall. A shortcut method of figuring the lateral pressure and sufficiently close for all practical purposes is to assume the lateral pressure per square foot at any depth as equal to one-third of the weight of a one foot square column of earth extending to the street surface above this depth. In addition to the bending, the sidewall columns take a direct load from the room beams of 83,000 lbs. Another practice in subway design is to assume the concrete in the wall between the columns to take up the direct load, within a certain limit, from the columns by adhesion, so that by the time the bottom of the column is reached, all the load is in the concrete. At the point of maximum bending moment in the column, which is somewhat over half way down the column, about half the direct load of the column has been transmitted to the concrete. It is the practice to design the sidewall column so that the direct stress left in the column (one-half the total load) at the point of maximum moment

plus the bending stress due to that moment shall not, when added together, exceed 25,000 pounds reduced by a rationalized formula when the direct load exceeds 150,000 pounds for a 12-inch column. In the present instance, the total direct load is 83,000 pounds and the moment approximately at the center of the beam is 1,150,000 inch-pounds. A 12 WF-45 pounds beam will satisfy the requirements. With the bearing power of the soil taken at 8,000 pounds per square foot, no footing is required for the sidewall. The two angles shown at the bottom of the sidewall column, Figs. 6 and 8, are not required to act as the base of the column as the concrete in the wall will have taken the full load from the column by adhesion by the time the bottom of the wall is reached; these angles only serve to help keep the column from falling over during erection. The interior columns are required to take a load of about 138,000 pounds. For this 6 WF 40 pounds columns will be used with the six-inch dimension set transversely. Such narrow columns are used to permit close spacing of the tracks, thereby keeping down the width of the subway, saving on the materials used in it and on excavation. In fact, the Bethlehem and Carnegie handbooks list these columns as subway columns, they having originally been rolled especially for this purpose. There is insufficient bearing area for the roof beams on all columns. Stiffener angles are accordingly used to supply the additional bearing required. The all-welded design, described later on, lends itself readily to the use of welded stiffener plates instead of angles. The 6-inch interior columns in the past, even with the riveted design in certain contract portions of the subway, had welded cap and base plates as seen in detail in Figs. 9 and 10. The cap plates for the interior columns shown in Fig. 3C were welded. On the other hand, a close scrutiny will show that no cap plates were used for the columns shown in Fig. 3A, riveted connection angles being used instead. Fig. 3C is a photograph of a portion of the subway known as Route 108, Section No. 9, where the steel work was done by the American Bridge Company. This company used welding as much as it could. On the other hand, Fig. 3A shows the steel in Route 108, Section No. 6. The McClintic Marshall Corporation, a subsidiary of the Bethlehem Steel Company, was the sub-contractor for the steel here. The comparative estimates forming a part of this paper are made on the basis of the use of welded cap plates in the riveted design of the past. Actually, as seen in Fig. 3A, much of the past work had riveted connection angles. On the latter basis there would be an even greater saving for the all welded design than is shown later on in this paper.

The sidewall columns, Figs. 7 and 8 are supplied with shop riveted connection angles at their tops as well as with the base angles, noted above, at their lower ends. The outer roof beams are field riveted to the tops of the sidewall columns.

The number of joints in the roof of the bent could be reduced by using longer beams. That is, instead of using a separate beam for each span, or four beams across the bent, two roof beams could be used, each beam to extend over two spans. Less joints means less shop and field work on the members. However, long beams cannot be used to effect such economy in a subway bent. The trench which is dug to contain the subway must be decked over in practically all cases to form a street surface for the maintenance of street traffic, Figs. 3A and 3B. In fact, the usual procedure is to lay the decking at the street surface before the trench is dug and then to undermine the decking, posts being used to support the decking as the excavation progresses down. When the excavation is finally completed,

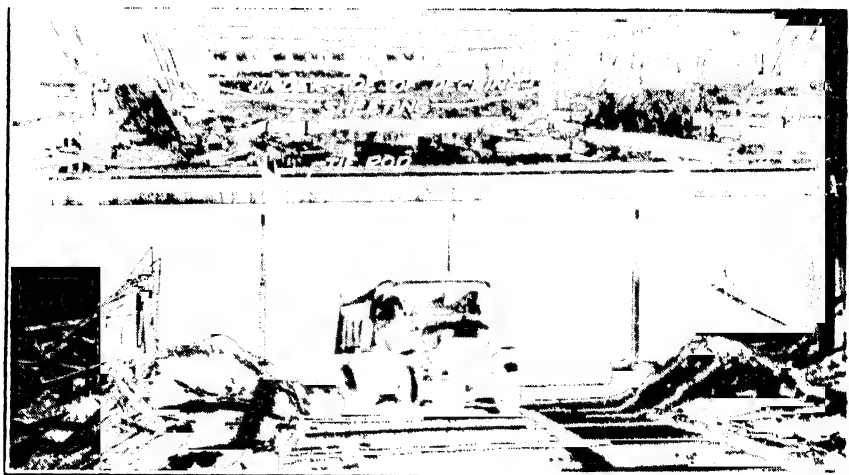



Fig. 3a. Typical riveted bent between stations.

there remains a deck supported on a complex system of temporary steel beams and girders. Also there is a tangle of water pipes, sewers, gas pipes, mail tubes, steam mains and electric ducts supported under the decking. All these obstructions under the decking make it troublesome to insert too long a beam through them into its final position in the bent.

The decking shown in Figs. 3A and 3B is unusual in that the decking beams are of sufficient size to span entirely across the cut, a distance of about 60 feet. Usually the decking beams are of smaller span requiring the use of intermediate posts which are a further obstacle to long span beams for the permanent roof steel. In this particular contract, the contractor's scheme of using his power shovels required that the excavation be entirely clear of posts. Because this contract ran through a sparsely settled section of the city, there are very few pipes and other utilities supported under the decking to interfere with erection.

Another objection to running the permanent roof steel continuously over two or more spans is because counter-moments are produced over the intermediate column or columns. This induces compression on the underside of the roof beam where there is but little concrete, Fig. 5. It will be remembered that the allowable stress was increased 25 percent because the concrete was assumed to act with the steel in compression.

Deformation of Bent—In Figs. 11 and 12 is shown in an exaggerated manner, the deformation of a subway bent produced by the loading.

Considering the steel to carry the whole load, the theoretical maximum deflection of the roof beams is one-quarter of an inch. Actually, field measurements have shown it to be less, because as pointed out, the concrete between the beams help to carry the load by a sort of hybrid reinforced concrete action. Further, the full street surface load of 600 pounds per square foot was most likely absent when the sights were taken. In deflecting, the ends of the beams become inclined to the vertical causing the beams to separate from each other at the tops of their abutting ends. Theoretically, the separation at the tops for the conditions shown is one-quarter of an inch. The portions of the flanges over the columns have their outer ends

lifting off the column, Figs. 11A and 12. In the riveted design, these deformations are taken up by the deformation of the rivets, connection angles and the flow of the metal in the main members beyond its elastic limit where the bearing value of the rivets is exceeded. The proposed welded design is so constituted that the deformation does not reach the welds but is taken care of elsewhere in the connection.

Welded Bent—It is better not to subject the welds to the prying action they would get if they were used to connect the bottom flange of a roof beam directly to a sidewall column. The prying effect which such a connection would have when the beam is loaded, can be seen in Figs. 11 and 11A where the extreme end of the roof beam can be seen lifting off the side wall column. To overcome such prying action, additional plates are required together with additional welding. As will be seen, however, the welded connection used practically eliminates the prying action. In the riveted connection, the give of the connection angles and other factors previously mentioned at the top of the sidewall column will permit the separation. For the welded connection it is proposed to use a type of flexible connection which will allow the end of the beam to lift off the sidewall column and still hold the adjacent portion of the beam for the purpose of taking care of the side pressure from the column.

The welded design is simple. Its essential part is a long plate which is kept weak enough in bending to be relatively flexible, thereby keeping down the prying action. All the field welding is flat. Not a single hole is used in the entire design. As can be seen in Figs. 11, 11A, 11B, 16 and 17, at the sidewall, the plate is welded to the top of the column but free of the beam where the latter comes over the column and separates therefrom when loaded. The plate is welded by 3/8-inch fillet welds to the column in the shop. The beam is welded in the field by 3/8-inch fillet welds to the portion of the plate which overhangs or projects beyond the column. As the roof beam bends down under the load, it bends down the overhanging portion of the plate with it. As the flange of the beam and the overhanging portion of the plate move down together, no separation is possible. The welds connecting them are, therefore, subjected only to shear from the side pressure. The overhanging portion of the plate also allows for the deformation of the sidewall column due to the effect of the side pressure of the earth, Fig. 11. In the riveted design, the bottom flange of the outside roof beam, Figs. 6 and 7, is riveted by means of a pair of clip angles to the top of the sidewall column. Enough rivets are used to transmit the thrust of 22000 pounds from the sidewall. In the welded design, two field welds each 4½ inches long are used to connect the bottom flange of the roof beam to the overhanging portion of the cap plate. Allowing for crater effect, the welded connection is good for 24,000 pounds thrust. The cap plate in turn is connected to the top of the sidewall column by two welds to each side of the web of the column, each weld being 3½ inches long. These welds are capable of taking the side thrust plus whatever upward pull is required on them to hold the cap plate down on the column while its overhanging portion is bent. The additional welding shown between the cap plate and flange of the column is for shipment. The long overhang of the plate may cause the latter to be knocked off in handling. Even with the smaller overhang of the cap plates shown in Figs. 3C and 9, a number came off in shipment.

The thinner the cap plate is kept, the easier its overhanging portion will bend and hence the less the upward pull on the welds to the web of

the column. As far as the transmission of the side thrust is concerned, a plate less than ⅜-inch in thickness would suffice, but it has been found by the fabricating companies in the case of the cap plates over the interior columns in the riveted design, Figs. 3C and 9 that if less than ¾-inch thickness is used, the plate will warp because of the welding. It will be remembered, that even in the present riveted design now in use, the cap plates are welded to the tops of the interior columns. Because of the warping, the cap plates are made ¾-inch thick. But the use of so thick a plate induces an appreciable upward pull, due to the prying action, on the welds to the web of the column. In order to reduce the pull, the cap plates are weakened in bending by slotting them as seen in Figs. 11A, 11B, 16 and 17. There is enough metal left in the plates after the slotting to take the side thrust of 22,000 pounds.

The slotting as shown in Figs. 11B and 12A is only one way of weakening the plate in bending on its overhanging portion. Instead of using the slot shown, the plate could be slotted or scored transversely, that is a groove as seen in Fig. 19A for its entire width could be cut into it. While this is more effective because the bending strength of the plate varies as the square of its thickness, and only as the first power of its width, yet it has an element of danger in that the depth of the groove is not so easily controlled. Unless extra precautions are taken, the groove may be cut too deeply, or the plate placed on the column with the groove upward. Both these conditions may lead to fracture of the plate when loaded.

The deliberate weakening of a plate or a member, to save the welding that must ordinarily be provided for secondary stresses, should have use not necessarily limited to the subway bent. Further, the use of the flexible plate connection, with or without the weakening, is a device which can be used elsewhere than in subway construction.

The riveted angle stiffeners, Figs. 3A, 3C, 7 and 9, of the riveted design are replaced by welded plate stiffeners, Figs. 17 and 20. There is no novelty in this fact by itself, as the welded stiffeners could have been used, theoretically at least, with the riveted design. Actually, welded stiffeners have not been used in the riveted design because it did not pay. Even the American Bridge Company, which favored welding to the extent of using it for cap plates on a job, did not on the same job weld the stiffeners, as can be readily seen in Fig. 3C. As most structural shops are at present constituted, it would not pay to weld the stiffeners to the beams where punching and riveting must be done on other parts of the beams. Therefore, it is fair to claim the saving accruing because of the use of the welded stiffeners, for the welded design.

The cap plates for the interior columns in the welded design are welded to the tops of the columns just as in the riveted design but are larger. In the riveted design, Fig. 9, the bottom flanges of the roof beams are riveted to the cap plate with a nominal number of rivets, the thrust from the sidewalls not bringing any load on them but being transmitted transversely across the bent by end to end bearing of the beams, the ends being milled. In the welded design, Figs. 12, 15, 19 and 20, each beam has its lower flange field welded to the cap plate of an interior column by two ⅜-inch fillet welds, each 5 inches long. The welds are figured at 3,000 pounds per lineal inch with ½ inch added for crater effect. They are designed to produce a tension splice for the lower flanges of adjacent beams of a strength equivalent to that of the 5½″ × ⅜″ × 1′-3″ web splice plates of the riveted design, Fig. 9, plus the splicing value produced by the four rivets through

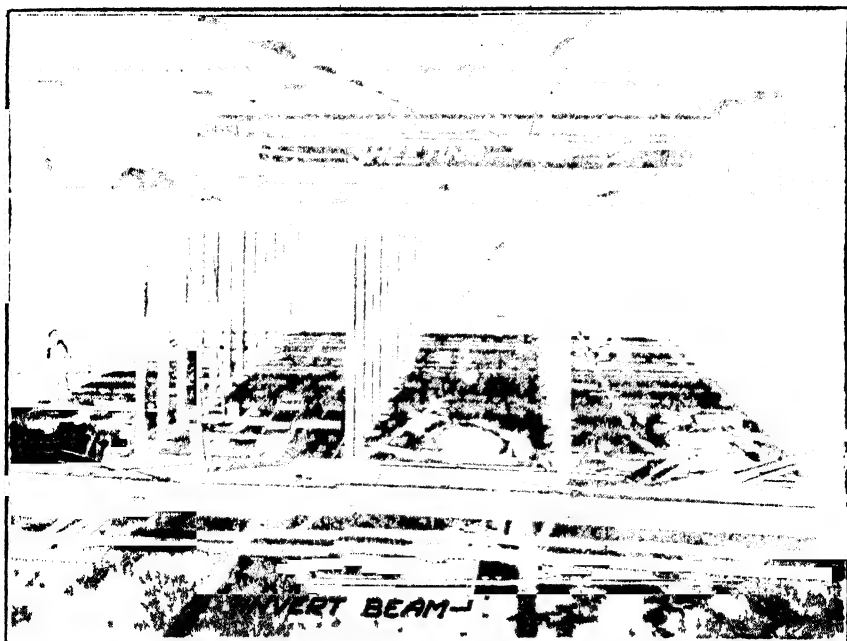



Fig. 3b. Stretch of subway with invert below ground water.

the 8″ × ¾″ × 1′ 2″ cap plate The reason for the splice is that in case of a derailment some columns may be knocked out The welding of the columns to the plates is made less than that of the plates to the roof beams, so that any blow against the columns will cause their separation from the plates rather than the plates from the beams While not of sufficient strength to take the bending, nor, as a matter of fact, are the beams themselves, over two spans, the splice plus the action of the concrete and the fact that no live load will be allowed on the roof after a derailment, all these conditions together, will allow the structure to hold up until temporary shoring can be used to replace the lost columns As a matter of fact, a derailment on the 7th Avenue Subway near 33rd Street some years ago knocked out five columns in a row and the roof held without damage

It is to be noted, that as the overhanging portions of the cap plates are deformed with the deformation of the beams, Fig 12, they deform in conformity with the beams so that there is practically no tendency for them to separate from the beams and induce a secondary stress in the welds to the beams Slots are used for the cap plates of the interior columns just as at the sidewall columns

In the riveted design, a pair of clip angles is used at the bottom of each sidewall column, Figs 6 and 8 As previously explained they are nominal, acting only to give some stability to the columns during erection A base plate, welded as shown in Fig 18 is substituted in the welded design for the clip angles As noted before for the stiffener plates, a welded base plate would have been permitted by the engineers of the Board in the riveted design, but the steel fabricators did not find it economical to shop weld a plate at one end of a beam and use a riveted shop connection at the other

end. The base plate for the interior columns, Fig. 10, is the same for both the welded and riveted designs.

Welded connections for a subway bent have a decided advantage over riveted connections in that they avoid erection difficulties caused by inaccuracies in the length of the roof beams or in the plumbing of the columns. In erecting a riveted bent, should these inaccuracies be present, the setting of the roof beams end to end might produce a cumulative error sufficiently great to prevent the holes in the bottom flange of the last beam from matching those of the column on which it is to set. The likelihood of this would be particularly great in the six-track subway of Fig. 3C. This would require the loosening of erection bolts and a readjustment of the members. In extreme cases new connection angles with differently located holes would be required. With welded connections, the beams can be welded to the columns wherever they should happen to come. This fact could be used to advantage to eliminate the required milling of the abutting ends of roof beams in the present riveted design. If trouble in matching holes is had at present, even with milled edges, the accumulated error would be greater with sawed edges. As seen in Fig. 9, it is a present requirement to mill the ends of the beams. The proposed welded design is conservative in that it maintains this milling. There is difference in thought among the engineers having to do with subway design as to the necessity of milling. One of the reasons advanced for it is that in case of a derailment, should interior columns be knocked out, as noted before, the tops of the beams will bear and form in each case the compression flange of an emergency beam, while the cap plate of the column and the splice plates will supply the tension flange. The only strength in tension that can be derived from the cap plate is that supplied by the two rivets fastening the bottom flange of each roof beam to the cap plate. Because the milling will allow the beams to bear at the top flanges, the neutral axis of the emergency beam will be high, thereby increasing the efficiency of the splice plates and cap plate in tension. However, in the welded design, the welding connecting each bottom flange of adjacent beams to the cap plate can be increased somewhat, increasing also the length of the cap plate, to compensate for the fact that without milling, the upper ends of the roof beams do not bear, the compressive side of the emergency beam being supplied by the concrete, resulting in a lowered neutral axis. The saving in milling is only a small part of what could be saved by the welded design should the milling requirement be lifted, as the writer believes will happen sooner or later. A very great saving could be had under these conditions by the welded design shown, in that the roof steel could be shipped, cut to length by the saw, directly from the mill to the job without the necessity of having it pass through the fabricating shop. This great saving would be offset to a small extent only by the necessity of field welding the stiffener plates.

Fig. 3D shows a bent which varies somewhat from the typical shown in Figs. 3A and 6 in that the 21 WF beams of the end spans run all the way over the interior columns, the 18 WF beams of the inside and shorter spans being connected by shear connections to the deeper beams. A certain limited amount of leeway is permitted the individual squad leader in designing his portion of the subway. In this particular case he preferred to keep his beams flush top so that the concrete arches between them, Fig. 5, would have their crowns a constant distance below the tops of the beams. If the proposed welded design were to be used, however, it becomes important

to have the beams flush bottom and have them meet at the center of the columns so that their bottom flanges could be welded to the flexible cap plate. This can readily be done. The crowns of the concrete arches do not necessarily have to have the same relation to the tops of the beams where adjacent beams do not differ too much in depth as in the instant case. In Fig. 3B, the deep beam for the left span must run across the right column as shown, otherwise too much eccentricity of load is thrown on the column. This bent then can be considered as typical, as is the case for about one-third of the bents of the subway.

Erection of Bents—To assist in the stability of the steel during erection, and before and during the time the concrete is poured, tie rods are used to tie in adjacent bents with each other, Figs. 3A, 3C, 4, 5 and 6. These rods serve no purpose in the completed structure. At present in the riveted design, holes are provided in the webs of the beams through which the rods are inserted. Each rod has a head at one end and is threaded for a nut at the other. It would detract from the welded design to provide holes for tie rods because of the extra operation and handling of heavy members involved. These would be the only holes in the welded bent. To avoid punching holes in the beams in the welded design, tie rods with hooked ends are used to engage the top flanges of the beams, Fig. 14. One end of the rod is bent over to form a hook and the other end is threaded. A small channel clip is slidably mounted on the threaded end of the rod and a nut is used to pull it up tight against the top flange of the beam. Note in Fig. 3C, the struts taking up the compression induced by screwing up the nuts on the tie rods between the nearest and the next to nearest bent.

In the welded design, because of the absence of holes in the members, there is no chance to use erection bolts. To provide for the temporary attachment of the beams to the columns, until the welding is done, clamps are used, Figs. 13 and 13A, for holding the bottom flanges of the beams to the cap plates of the columns. Only a limited number of clamps are required as they can be taken off and used over again as the erection progresses. Because clamps are not as good as bolts, a certain amount of wood scantling should be used as bracing between the bents with additional tie rods between the bottom flanges, until the final welding. It is common practice with welded structures not over one story in height to use clamps in erection. An allowance has been made in the estimate for the extra difficulty had in the use of clamps.

Cost Data—A factor that will tend to reduce the overhead on field welding is that on many subway jobs the contractor, or subcontractor, must have welding equipment on hand anyway, because it is the practice to weld the system of beams supporting the temporary street surface for more or less continuity, so that the posts can be shifted as the excavation progresses. A temporary street surface, Figs. 3A and 3C is required in most portions of New York so that there is no interruption in street traffic while the subway construction and excavation are carried on underneath. The system of decking shown in these figures, however, does not require the welding noted above.

A cost record, about the year 1938, of a sample quantity of 225 field rivets on the Sixth Avenue Subway is as follows: The 225 rivets were just a portion of a much larger amount of riveting the gang was doing. The apprentice noted spent half his time with this gang and half his time with another gang.

Fig. 3c. Steel for 6-track subway.

4 Structural Ironworkers 1 day @ $16 each	$ 64
Apprentice for ½ day	5
	$ 69
15% insurance on labor, and taxes	10.35
Plant, etc.	9.00
Material	7.00
	95.35
Overhead @ 20%	19.07
	114.42
Profit 10%	11.44
Cost per rivet 56¢ Total	$125.86

The cost of field riveting for the typical bent shown in Fig. 6 runs higher than this because of the more frequent shifting of riveters from place to place, each location having only from four to six rivets in a cluster. The riveting in the estimate just given has a higher concentration of rivets, as at a station, where the roof beams instead of resting on a column and being fastened with four rivets, Fig. 9, have shear connections to longitudinal girders with 10 to 12 rivets at each location. On the Queens Plaza Station contract in 1937 for elevated work, the contractor bid $1.00 per field rivet for a job having 1,000 field rivets. For the Culver Line Ramp Connection in early 1941 for work partly in subway and partly overhead the contractor also bid $1.00 for each field rivet. The total number of field rivets in this job was 800. For riveting, as compared to welding, there is more detailing in the drafting room and the locating of the holes requires more measuring and laying out on the steel itself. On the basis of the above data, $1.00 per field rivet is used in the estimates following.

On the basis of the cost estimating given in the "Procedure Handbook of Arc Welding Design and Practice," a very conservative estimate of the shop welding is 4¢ per inch of 3/8-inch fillet weld. The field welding, which is all flat, is conservatively taken at 8¢ per inch of 3/8-inch fillet weld. As noted above for the riveting, there is much climbing around from location to location for the field welding resulting in a very low operating factor. These prices also include overhead, insurance and profit. Field workers classified as structural ironworkers on the Sixth Avenue Subway in 1937 were paid not less than $1.65 an hour pursuant to the provisions of the Labor Law of the State of New York. It is assumed that all prices will be post-war prices.

Even a considerable relative change in the selected prices favoring riveting would still show a substantial saving for the welded design.

Cost Estimates—The following are the estimates of cost of the riveted and welded designs. Where items are common to both designs they are omitted from both estimates. Such an item, for example, is the handling of steel for erection. The prices are assumed post-war normal prices.

Cost Estimate for Riveted Bent for 4-Track Subway

Joints at Interior Columns

Item	Quantity	Cost
3 Cap plates 8″ × 3/4″ × 1′-2″	71.10 lbs.	
6 Splice plates 5 1/2″ × 3/8″ × 1′-3″	52.5	
12 Stiffener angles 3 1/2″ × 3 1/2″ × 3/8″ × 1′-7″	161.0	
	284.6 lbs. @ 2.7¢* —	7.68
Punching rivet holes in beams, splice plates, cap plates and stiffeners and holes in roof beams for tie rods	220 @ 17¢	37.40
Reaming holes in cap plates	12 @ 20¢	2.40
Field rivets	42 @ $1.00	42.00
Shop rivets	30 @ 20¢	6.00
	$95.48	

Connections at Side Wall Columns

Item	Quantity	Cost
4 Stiffener Angles 3 1/2″ × 3 1/2″ × 3/8″ × 1′-7″	53.7 lbs.	
8 Angles 6″ × 4″ × 7/16 × 8 3/4	83.5	
	137 2 lbs. @ 2.7¢*	3.70
Punching rivet holes in beams and angles	116 @ 17¢	19.72
Field Rivets	12 @ 1.00	12.00
Shop Rivets	28 @ 20¢	5.60
	$41.02	
Handling of steel in shop for operations		9.00
		$145.50

*Price of steel delivered at shop.

Prices for labor include cost of detailing, laying out and measuring for holes, overhead, insurance and profit.

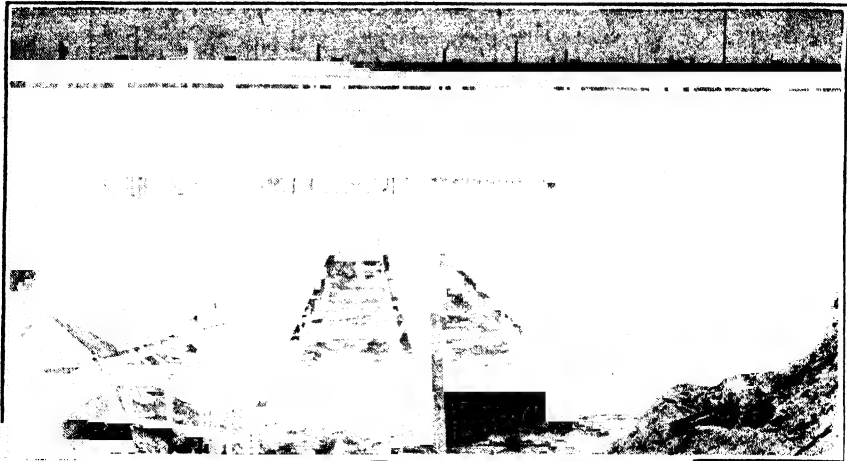



Fig. 3d. Riveted design.

Cost Estimate for Welded Bent for 4-Track Subway

Joints at Interior Columns

3 Cap plates 10″ × ¾″ × 1′-6″	114.8 lbs.	
12 Stiffener plates 3½″ × ⅜″ × 1′-7″	84.5	
	199.3 @ 2.7¢*	$ 5.38
Field welds—⅜″ fillet—54″ @ 10¢		5.40
Shop Welds, Stiffener plates ⅜″ fillet	264″ @ 4¢	10.56
Slotting cap plates—12 slots @ 20¢		2.40
	$23.74	

Side Wall Columns

4 Stiffener plates—3½″ × ⅜″ × 1′-7″	28.2	
2 Cap plates—10″ × ¾″ × 1′-6″	77.0	
2 Base plates—10″ × ¾″ × 1′-1″	55.1	
	160.3 @ 2.7¢*	4.33
Slotting cap plates—4 slots @ 20¢		.80
Field welds—⅜″ fillet—18″ @ 10¢		1.80
Shop welds—⅜″ fillet—132″ @ 4¢		5.28
	$12.21	
Handling of steel in shop for operations		5.00
Additional cost of hooked tie rods		3.00
Erection clamps and added wood bracing**		8.00
	Total	$51.95

*Price of steel delivered at shop

**Clamps can be used over again for other bents

Saving of Welded Over Riveted Bent for Four-Track Subway

Cost of riveted bent	$145.50
Cost of welded bent	51.95
Saving	$ 93.55

A 4-track bent weighs 3.7 tons. Therefore the saving per ton is $25. The saving per mile of subway composed completely of typical bents spaced 5 ft. center to center is $100,000.

Cost Estimate for Riveted Bent for 2-Track Subway

Joint of Interior Column

1 Cap plate 8″ × ¾″ × 1′-2″	23.7 lbs.	
2 Splice plate 5½″ × ⅜″ × 1′-3″	17.5	
4 Stiffener angles 3½″ × 3½″ × ⅜″ × 1′-7″	53.7	
	94.9 @ 2.7¢	2.56
Punching rivet holes in beams, splice plates, cap plates and stiffeners and holes in roof beams for tie rods	76 @ 17¢	12.92
Reaming Holes in cap plates	4 @ 20¢	.80
Field rivets	14 @ 1.00	14.00
Shop rivets	10 @ 20¢	2.00
Side Wall Columns		
Same as for 4-track riveted bent		41.02
Handling steel in shop for operations		5.00
	Total	$78.30

Cost Estimate for Welded Bent for 2-Track Subway

Joint at Interior Column

1 Cap plate 10″ × ¾″ × 1′-6″	39 #	
4 Stiffener plates 3½″ × ⅜″ × 1′-7″	28	
	67 # @ 2.7¢	$ 1.81
Field welds—⅜″ fillet 18″ @ 10¢		1.80
Shop welds—Stiffeners 88″ @ 4¢		3.52
Slotting cap plate 4 slots @ 20¢		.80
Side Wall Columns		
Same as for 4-track welded bent		12.21
Handling of steel in shop for operations		3.00
Erection clamps* and added wood bracing		5.00
Additional cost of hooked tie rods		2.00
		$30.14

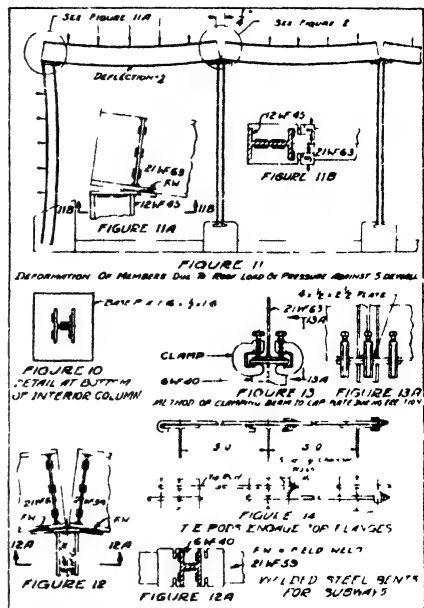
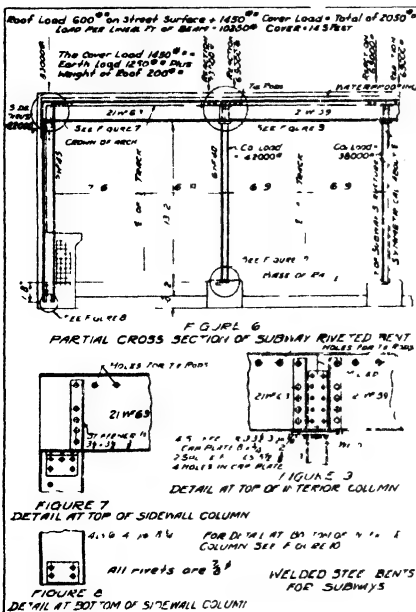
*Clamps can be used over again for other bents.

Saving of Welded Over Riveted Bent for 2-Track Subway

Cost of Riveted bent	$78.30
Cost of Welded bent	30.14
	$48.16

A 2-track bent weighs 2.2 tons. Therefore, the saving per ton is $22. The saving per mile of subway composed completely of typical bents spaced 5 ft. center to center is $51,000.

Other Types of Bent—Figs. 6 and 15 each show a portion of a bent for a 4-track subway. The same principles of design apply to a 2-track subway. In the latter case there is only one interior column, two roof beams and two sidewall columns. A portion of a 6-track subway is seen in Fig. 3C.

The bents discussed thus far show no beams in the floor of the subway. Whenever the floor or invert of the subway is in earth and definitely known before the excavation is done to be below ground water level, a steel beam invert, Figs. 3B and 21, is used for the bent, the beams extending in a line under the columns across the full width of the bent just as the beams rest on the columns in the roof. The savings of the welded design, just as for the roof beams, can be made in addition for the invert beams. This means that the savings over a corresponding riveted bent for a 4-track subway with invert beams is $187 or double that of a 4-track bent over a corresponding riveted one having an invert without beams. Where ground water is encountered in such localities where its presence was not known definitely in advance of the excavation for the subway, a reinforced concrete invert is used instead of a structural steel and concrete one, because if the structural steel had been ordered in advance and then no water was encountered, such steel would be wasted. The structural steel and concrete is preferable to a reinforced concrete one because it is cheaper in normal times. It is cheaper because by using shallow heavy beams much concrete and excavation can be saved. Note in Fig. 3B that the invert beams are shallower than the roof beams. In figuring the invert, the live load, that is the street surface load, 600 lbs. per square ft. Fig. 6, is neglected.

Figs. 6, 7, 8 and 9, (left). Figs. 10, 11, 11a, 12, 12a, 13, 13a and 14, (right).

Overcoming Objection to Welding—To help overcome any reluctance to the use of welding, consideration should be given to the fact that the roof beams rest directly on the columns so that even with poor welding no failure

could occur from downward load. It should be remembered that the roof members cannot move sideways because of the concrete between them. Further, an occasional poor weld would not make the structure too weak to take the side pressure, because the remaining welds at the connection, just as in the case of rivets, would take additional stress, the effect of friction between the roof beam and the sidewall column would supply resistance and the fact that the subway structure can be thought of as an elongated box or conduit where each bent can act to help out its neighbor rather than a succession of isolated bents. This was proved in the derailment noted before where five successive interior columns were knocked out. In other words, the point is here made for those who do not trust welding, that even if all the welds were no good, there would be no failure as far as the effect of downward load is concerned, and no failure from side pressure, even if there were occasional defective welds. It seems reasonable to assume, in view of the present development in the art, that there is only a likelihood of an occasional defective weld. Trained welders will be plentiful after the war because so many men are learning this trade for war production.

While the design given herein is for welding the typical section between stations, the welding problem is readily solved for the many shear connections, heavier steel work and larger stresses encountered at the stations, but because of the reluctance of those having the final say to use welding at all, it is thought best to start with the simplest form first. This is not so much of a limitation as it sounds, because two-thirds of the length of the subway is made up of bents of this simplest form.

Proportionate Cost Savings—The saving in weight of a welded bent over a riveted one is only about 2 percent, the principal saving being in labor.

As seen from the cost estimate for riveted bent, the saving for a 4-track welded bent is $94. Such a bent weighs 3.7 tons. Therefore the saving per ton of steel erected is $25. It must be remembered that the riveted bent chosen as a criterion was an average one, the average being chosen from a consideration of many miles of subway already built. The corresponding saving for a 2-track bent is $48 per bent. Such a bent weighs 2.2 tons. Therefore the saving per ton of steel erected is $22.

In order to arrive at a proportionate cost saving, it is necessary to fix a price per ton of subway steel erected. This will be done by considering the contract prices bid on several miles of subway during the years 1928-1930. It is believed that post-war prices will be about on this level.

The following is a tabulation of the contract prices for furnishing and erecting steel on a few sections of subway forming parts of the Independent System.

Queens Boulevard and Hillside Ave. Subway

Route	Section	Tons	Price per Ton
108	5	13,200	$ 94
"	6	12,500	110
"	7	6,800	106
"	8	14,820	95
"	9	9,700	99
"	10 and 11	7,800	90

Fulton St. Subway, Brooklyn

Route	Section	Tons	Price per Ton
110	1 and 2	14,080	$101
"	3	5,150	105
"	4	7,700	100
"	5	5,520	95

On the basis of these figures, it is fair to assume a price of $100 per ton for the riveted steel. For a 4-track bent, the saving of welded construction being $25 a ton, the proportionate cost saving is 25 percent. Likewise for a 2-track bent, the saving for welded construction being $22 per ton, the proportionate cost saving is 22 percent.

The saving per lineal foot of subway, remembering that the bents are five foot centers, for a 4-track subway is about $19, and for a 2-track subway about $9.50 or at the rate of $100,000 per mile for the former and $50,000 per mile for the latter.

Gross Savings—Plans are now being prepared for several short stretches of subway, so that after the war emergency, work can start on them without delay. The welded design could be used for portions of them as follows:

Extension of Fulton Street Line—Grant Ave. to 106th St. Queens.

Welded design could be used where the tracks are on one level between stations except crossovers. This is for a distance of 2,240 feet. About two-thirds of this has invert below water. It is a 4-track subway, Fig. 21 applying to the part below water at twice the saving per bent over that above water. Saving would be $70,000.

Connection for 60th St. Tunnels to Queens Boulevard Line.

Final layout not yet decided. A proposed scheme was in accordance with

FIGURE 15 WELDED BENT (ABOVE WATER)

FIGURE 16

FIGURE 17 DETAIL AT TOP OF SIDEWALL COLUMN

FIGURE 18 DETAIL AT BOTTOM OF SIDEWALL COLUMN

FIGURE 19 DETAIL AT TOP OF INTERIOR COLUMN

FIGURE 19A

FIGURE 20

WELDED STEEL BENTS FOR SUBWAYS

FIGURE 21— WELDED BENT (INVERT BELOW WATER)

FIGURE 22 DOUBLE DECK WELDED BENT

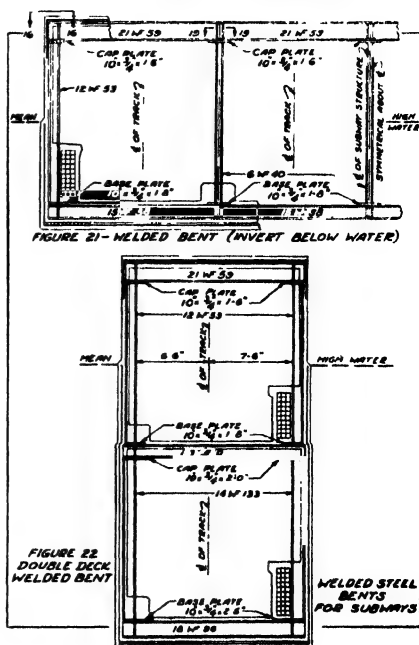
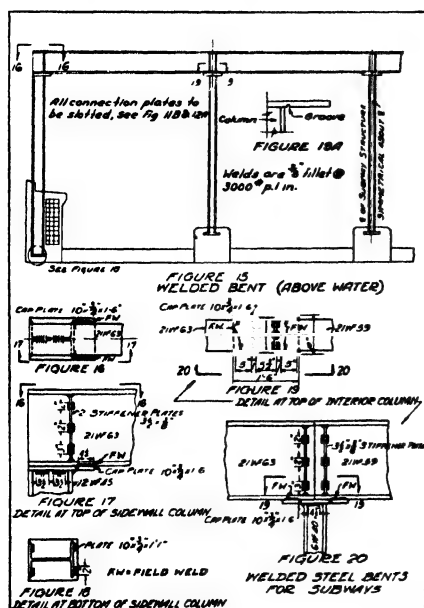
WELDED STEEL BENTS FOR SUBWAYS

Figs. 15, 16, 17, 18, 19 and 20, (left). Figs. 21 and 22, (right).

Fig. 22. If this scheme be selected, 2,400 feet of it will apply. Saving would be $52,000.

Connection from the Culver Line to the West End Line via Ft. Hamilton Parkway.

Two-track line above water. About 3,840 feet of it is suitable for the welded design. Saving would be $37,000.

Connection from Lenox Ave. Locals to 8th Ave. and 162nd St.

Two-track line. About 2,920 feet of it is suitable for the welded design. One-half of it is under water. Saving would be $42,000.

There would be a total saving of $201,000 if welding instead of riveting were used for the above noted projects.

In addition to the subway projects for which detailed plans are now being prepared for immediate post-war work, New York has an extensive program of future subway construction. A study of the present subway systems will help arrive at an idea of the possible extent of use of the welded design in future subways.

There are three systems of subways in New York City which have been constructed in the last forty years, namely:—the Interborough Rapid Transit Company, The Brooklyn-Manhattan Transit Company and the Independent System. All three systems were built by the city, but until recently only the last was operated by it. The Independent System is the latest one to be built.

The following table gives the approximate mileage of these systems:

System	Route Length of Subway	Length of Single Track
IRT	43 miles	130 miles
BMT	29 miles	82 miles
IND	53 miles	185 miles
		Total 397

No welding at all was used for the bents of the IRT and BMT systems. They were built too long ago. In the Independent System, which has been recently built, except for some occasional welding of cap and base plates to columns, no welding was used.

Contrary to popular belief, very little subway construction for urban railroad traffic is of the ring type having a cast iron or steel liner. This is used only in deep tunnel in earth. Even under a river, when rock is encountered it is not used, a concrete lining being used instead.

Of the 53 route miles of the Independent System, about 9 are of special construction including some of ring type and about 10 are occupied by stations, leaving 34 miles or about two-thirds of the total of a type adapted for the proposed welded design. It is reasonable to assume that about the same proportion of the route mileage of future subways will be suitable for the welded design.

The 53 route miles of the Independent System consist of 39 miles of 4-track and 14 miles of 2-track line, making about 73 per cent of 4-track line. Of the 125 route miles of all three present systems, about 73 are of 4-track and about 52 are of 2-track construction, giving about 59 per cent of 4-track construction.

It appears from studies made that for the first 15 years after the war, about 50 route miles of subway will be built, after that, in the course of 25 years more, an additional 100 route miles. Although the analysis given above shows that in the past about 59 per cent of the subway was of 4-track

construction, the gross saving on future construction will be made conservatively on the basis of 40 per cent.

Remembering that the welded design given herein applies only to two-thirds of the route mileage, the gross savings for the next 15 years would be:—

50 miles × 40% (4-track) × ⅔ @ $100,000 per mile	$1,333,000
50 miles × 60% (2-track) × ⅔ @ 50,000 " "	1,000,000
Total........	$2,333,000

The gross savings for the subsequent 25 years or for an additional 100 route miles on the same basis would be $4,700,000, making a total saving for the next generation of about $7,000,000.

Other cities are considering subways. Boston and Philadelphia have subway systems. Chicago has made a small beginning. Detroit and San Francisco have plans. For years there have been studies made for a large suburban and interstate transit system connecting New York City and vicinity with adjacent New Jersey territory. A considerable portion of this system would be in subway.

Because of the nature of the structure there is no question of increase in service life or efficiency of the welded bent over that of the riveted one. The welded bent has the social advantage of welding in general over riveting in that it is noiseless, so that people living in the vicinity of subway construction will not be annoyed by riveting hammers. A large proportion of subway construction passes through important congested areas where noise is undesirable.

The opinions expressed in this paper are the personal ones of the author.

Chapter XI—Arc Welded Sculpture

By Fred Clarke,
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Fred Clarke

Subject Matter: A procedure for building up a statue from four photographs of a model. The parts of the figure are built up by a combination of arc welding, heating and forging. To date, two 8-foot statues have been completed, one entitled, "Man of Industry" and the other of Winston Churchill. The cost of the first was $392.75 and of the latter $523.60.

In the first part of this paper the author explains why we started in arc welded sculpture.

To assist in this, the building of our first statue is described briefly. This was planned and constructed in June 1939.

The rest of the paper is devoted to the statue of Winston Churchill. This latter statue, presenting many difficult problems over our first attempt, was planned and constructed in June 1941. A large memorial with a group of statues was planned but has been put aside for the present due to steel priorities.

As welding instructor in a technical school, the writer is forever confronted with the perplexing problem of designing projects that will suitably illustrate the subject matter being taken—projects that will supply the correct type of practice-welding and lastly, projects that are suitable for display at the exhibition of student work that is held at the end of the school year. This last consideration is the most difficult.

Small individual projects such as practice-pieces in the many types of arc welding handle the teaching portion of the project work. Fabrication of bench vises, grinder stands and other pieces of equipment, supply the students with suitable projects for practice of setting up, fitting, study of effects of expansion and contraction and many of the technical phases of arc welding. However, this type of project is not the best for display purposes. Good welding has an appeal and interest to the mechanically-minded man, but means very little to the man following non-mechanical lines, or to the ladies. Our problem then, was to endeavor to design a project using arc welding, one that would not be of a mechanical nature, something that would appeal to everyone. But it must necessarily embody sound welding practice and be practical.

The art of welding is an often-used phrase—then, why not use welding in art. Objects of art are pleasing to everyone. The ideal display project then, must be some work in one of the arts. It is obvious that the art of Sculpture is the easiest to be adaptable to the arc welding process.

Sculpture, the art of designing in relief or in the round, is one of the oldest arts practiced by man. Down through the ages, man modelled or carved objects of beauty or everyday interest. A large number of materials and methods were used in this work. Fundamentally, they can be divided into two classes; one in which solid materials—such as wood or various kinds of stone, are cut, chipped, or rubbed into the desired shape. In the other, plastic materials such as clay or wax are moulded into shape. This latter method, however, produces fragile objects, necessitating a further process of casting the finished sculpture in bronze or some other suitable metal for permanency.

Fig. 1. Photographs for statue, "The Man of Industry."

Sculptures are essentially for display purposes. Museums, famous buildings and art collections have lavish displays of the work of old masters, some of whose names are long since forgotten. Parks and other public places exhibit the work of our modern sculpture in the form of memorials, fountains, or statues of prominent persons. Into this field of noble art we are going to fit modern practice to sculpture in steel, using the arc weld instead of chisels or moulding tools.

Arc welding is quickly displacing the rivet and bolt and has outmoded the idea of casting machine parts in weak brittle metals. Strong ductile units are quickly and easily fabricated; in fact, the arc weld with its speed and efficiency is changing the entire field of production in metals. More and more of the articles of our everyday life will be adapted to manufacture by arc welding.

The field is unlimited. I am endeavoring to show in this paper that arc welding could have a definite place in modern sculpture. If it can be made of metal, it can be made by arc welding.

It is a recognized fact that the best way to build any structure is to have a drawing made first, so that proportions and measurements may be worked out. Our first problem then, was to make some picture from which to work.

This portion of the job was easily solved. A model was posed and four photographs were taken as in Fig 1

The photographs in Fig 1 were taken at equal distances away from the model and all at the same height from the ground This, to enable us to measure directly from the pictures To facilitate measuring, a special scale was made. This scale was marked to divide the height of the figure in the photographs into 96 parts The finished statue was to be eight feet tall so, one graduation on the special scale was transformed to one inch on the statue. These measurements are all taken from flat pictures, having no equivalent to the top view of a blue print However, by taking measurements from two or more views, any length can be worked out

Our first attempt at arc welded steel sculpture proved interesting and the results were most gratifying This statue, (See Fig 2) "Man of Industry," is the figure of a man eight feet tall He gazes intently at the micrometer held in his hand as he measures a small crankshaft
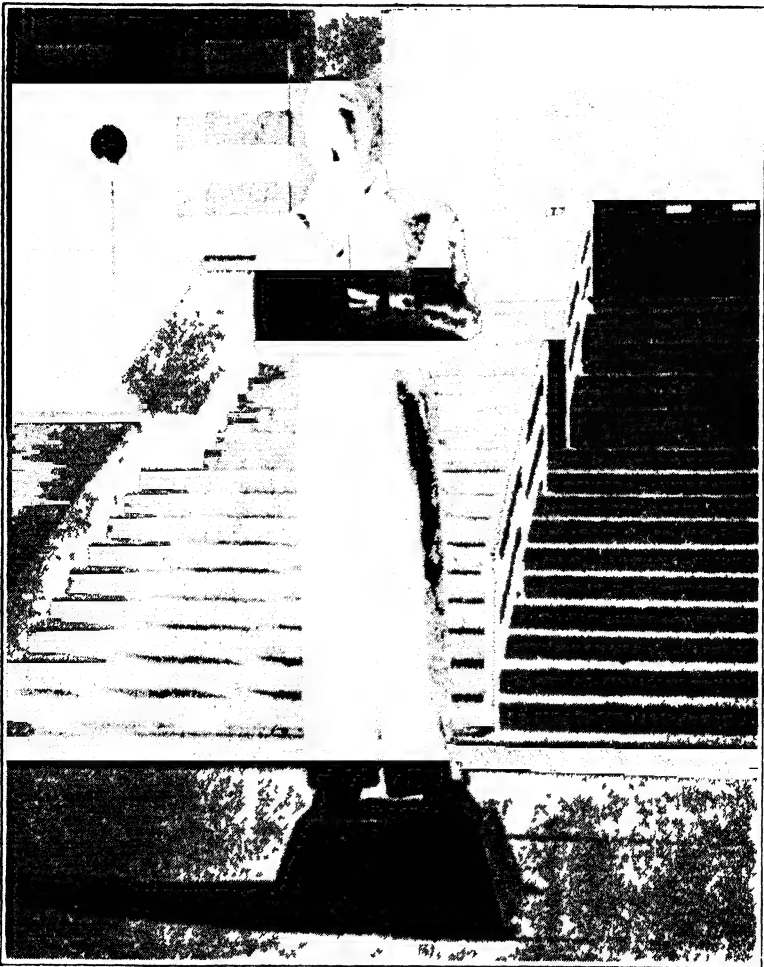
Fig. 2. Statue, "The Man of Industry."

Our "Man of Industry" created a sensation when put on display. It was the center of attraction at the school exhibition, and the City's annual fair. The Park's Board asked that it be placed permanently in one of the public parks. Our school board, however, decided that it would be more to their liking to be placed on a suitable foundation on the Technical School grounds, where it stands at the present time.

Four student welders under the supervision of the writer, were put on this job and carried it through to completion—none of these, having had any previous experience in this particular class of work.

All plating of the figure was done using $3/16$-inch mild steel plate. This size seems most suitable, having sufficient stiffness to be forged without the tendency of wrinkling which would occur with thinner material. It is also light enough to be shaped easily into any compound curve when heated.

Fig. 3. Photographs for statue of Winston Churchill.

The plating proceeds as follows:

1 Measurements of the parts being worked upon are taken from the photographs using the proportional scale.

2. A piece of plate is cut to these measurements leaving extra metal all round; this allows extra metal for working and is trimmed later, ensuring close fit-up.

3. All simple bends are made on the plate using a hydraulic press.

4. The piece is fitted, by trimming one edge (with a cutting torch) to fit one side only.

5. The plate is positioned so that a portion of this joint may be welded.

6. Braces are welded in tying the plate to the inner frame, at any point that is at the correct distance from the center.

7. Compound curves are made by heating the metal in small areas at a time and hammering. Working the piece slowly to the desired shape.

8. The plate should lap the pieces next to it, due to the extra metal that was allowed. This extra metal is now cut off, using the cutting torch. The metal is then hammered so that the joint is flush.

9. All joints are welded.

10. Small intricate parts that would be difficult to shape by bending or forging, are formed by building up the desired shape, using small electrode.

11. Built up metal may be heated with a torch and finished with a hammer.

It will be understood, of course, that the making of this statue was not a commercial venture, being primarily a school project.

We are able to keep our costs quite low, as most of the steel used is either donated, or taken from the scrap pile. Student labor costs nothing, and welding supplies are obtained at a liberal discount. However, to make up a cost sheet that would present a true picture of cost in a commercial way, the writer has disregarded our low prices and donations of materials, and figured time and material at current market prices. No overhead cost, or profit is shown in these figures.

Cost of Man of Industry

Item	Cost
3/16 mild steel plate—for plating figure—800 lbs. @ 8¢	$ 64.00
One quarter (1/4) mild steel plate—for base—150 lbs. @ 8¢	12.00
3 inch tubing for inner frame—75 lbs. @ 12¢	9.00
Shield arc electrodes—60 lbs. @ 17¢	10.20
Bare electrodes for hair—8 lbs. @ 9¢	.72
Current for arc-welder @ 15¢ per hour—52 hours	7.80
Labor for welder—130 hours @ $1.25	162.50
Oxygen for heating and cutting—1260 cubic ft.	18.90
Labor for helper—133 hours @ hours @ 50¢	66.50
Acetylene for heating and cutting—940 cubic ft.	18.80
Paint—3 quarts @ $2.35	7.05
Buttons. Turning in lathe—1 hour @ $1.50	1.50
Micrometer. Turning in lathe—3 hours @ $1.50	4.50
Photographs	2.80
TOTAL	$386.27

After having had such excellent results from our first statue, we decided to attempt something more difficult. We would try a statue of some prominent man.

This would have to be just right; it would have to look like some definite person. Winston Churchill, Prime Minister of Great Britain, seemed the ideal subject. No stronger character or more colorful man has ever lived. We would make the Man of Iron into an "Iron Man."

First a number of photographs of the Prime Minister were collected from newspapers and magazines. These were studied. By doing this we were able to judge the approximate height and weight of Winston Churchill. By careful check of a number of pictures, it was possible to decide his natural stance. With this to work on we located a man having the right height, weight and build, to act as a model. He was dressed in the style of clothes usually worn by the Prime Minister. He was posed and four photographs were taken, (See Fig. 3). This of course, would not do for work on the face and head. Photographs must be especially posed if measurements are to be
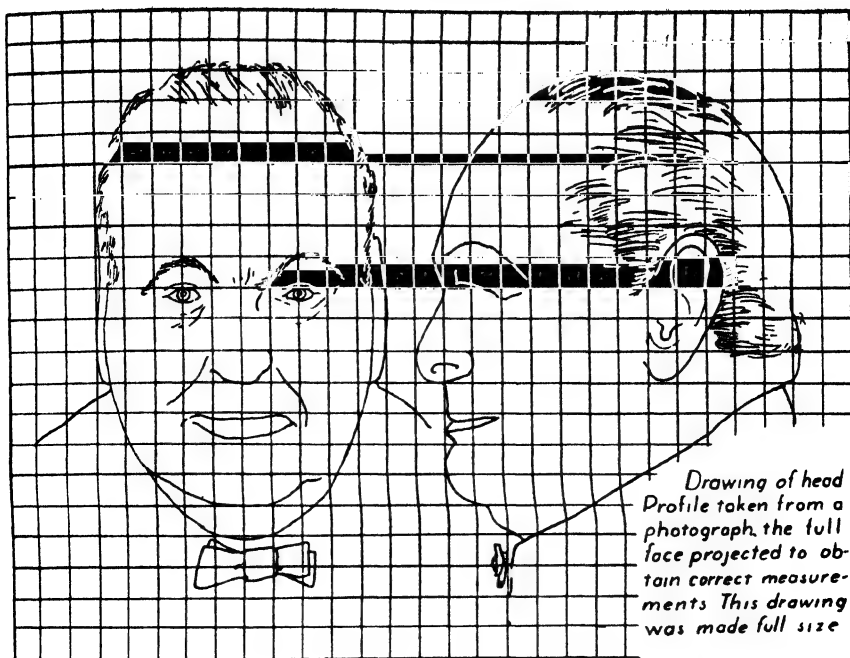
Fig. 4. Scale drawing for full-face view.

taken from them We had only one view of Winston Churchill's head, that appeared to be taken at the right angle of our purpose—this was a profile view.

Using this picture, we made a scale drawing and obtained the measurements for a full face view, (See Fig. 4). This drawing was easily made by ruling the photograph into squares—the squares being drawn to scale, one square on the photograph proportioned to equal one square inch on the drawing. This drawing was made full size for the eight foot figure. From the photographs a picture of the model was drawn minus the head.

A picture of the head proportioned to the size of the photographs was then drawn in, (See Fig. 5). This composition picture with Winston Churchill's head was used to obtain measurements for correct relations between the head and the body. A proportioning scale was used as with the first statue.

The building of the statue is carried on in a carefully planned manner—constructing and assembling the parts in the most convenient sequence, so that one part when completed will not interfere with the making of the next. The planning of various statues would differ in sequence of building. On this one, it was most convenient to follow this course:

1. The pedestal
2. The inner frame
3. Shoes
4. Trousers
5. Head
6. Coat
7. Sleeves (half)
8. Hands
9. Finish sleeves
10. Buttons and trimmings
11. Grind
12. Paint or finish

A detailed description of the construction follows:
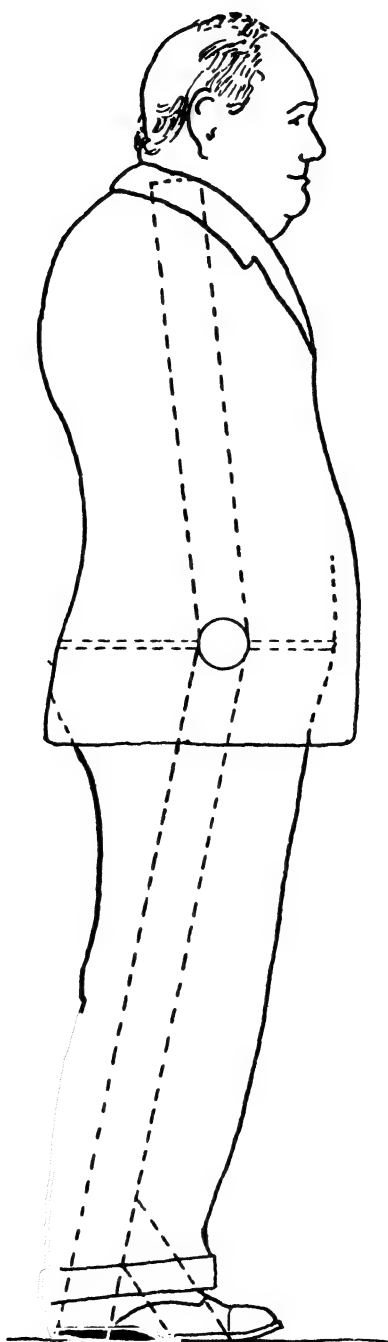
Fig. 5. Head and body of Churchill statue.

The Pedestal—A piece cut from an old steam boiler was used for the upright. This measured three feet ten inches high. Its diameter was increased at the base by adding a step all around. The top was bridged across with pieces of heavy angle iron to make a support for the statue. The top edge was heated and forged round to finish that portion. A large slab was then cut away and a flat plate fitted in and welded to form a surface for the inscription. The letters were cut out of quarter (¼)-inch plate and holes drilled through them in a number of places.

Quarter (¼)-inch steel pins were welded into the holes. The pins were put through holes previously drilled in the inscription plate, and welded on the inside. This makes the letters stand out in relief with no welding visible. A plate was then fitted into the top of the pedestal. This plate is not welded to the pedestal, but is held in place by three screws drilled and tapped into the supporting angle iron. The statue is then welded to this plate. This makes it easily detachable to facilitate moving.

Before starting the actual figure, an inner frame made of three inch steel tubing was constructed to carry the weight and form a rigid structure for the foundation. By consulting our drawn picture, (See Fig. 5), a frame was designed to support the figure and be in the most convenient position for bracing the plates. This frame was then welded to the plate on top of the pedestal, (See Figs. 6 and 7), and angle braces were put on to stiffen the joint —these angle braces being covered by the shoes. A cross-section just below the waistline of the figure was plotted out referring to the four photographs for measurements. A piece of quarter (¼)-inch plate was cut, this being the center brace for the body. This plate was then welded to the frame at the correct height—this assisting greatly in assembling the trousers. Two circles are welded on to the upright legs, to hold the trousers at the cuffs. These circles are not welded until after the shoes have been completed.

Shoes—A piece of ⅜-inch plate is cut to the exact shape and size of the sole of the shoe—the length and width and height being measured from the photographs. This piece is bent in a press to the correct shape. Four pieces were then cut for the heel, these pieces being stacked to make the desired height. Holes are cut through the heel-plates and a hole and slot through the sole-plate, to allow the inner frame to pass through, to be welded to the top of the pedestal-plate. These parts naturally must be formed and slipped on before the inner frame is welded. Soles and heels are then positioned on the pedestal plate and welded through holes to the base plate. The piece at the back of the toe-cap is made next. This is cut roughly to shape, turned in at the lower edges, and tacked into place. It is then heated with an oxy-acetylene torch and forged into shape, the welding is then completed from the inside. A piece is then cut to shape to make the back and sides of the shoe. This piece is also bent inwards at the bottom, where it contacts the sole, a portion being brought into shape and welded on the inside. The balance is then heated, a few inches at a time and forged into shape, welding as it is lined up. The part around the heel is welded flush with the edge of the sole plate, allowing the plate to curve outwards and upwards; the portion to the front of the shoe is about one quarter (¼) of an inch in from the outer edge of the sole. A tongue is welded in. Then the sides are heated and forged down, no welding being necessary at this point.

The toe-cap is the most difficult part of the shoes, as welding is carried on from the inside—the toe-cap being made of one piece forged partly to shape, a cut is made in the top and the metal opened to facilitate welding

to the sole from the inside This opening is then heated and hammered, closed and welded This cap laps the part of the shoe next to it.

No shoe laces were needed on this statue, as the trouser cuffs come low over the shoe tops On the Man of Industry, laces were made using iron wire, flattened to the correct shape and threaded through drilled holes Short pieces were used, tying two holes together These were tacked into place with the arc

Trousers—These are made of long narrow plates extending from the cuff ring just above the shoes, to the plate attached to the inner frame below the waist, with the exception of the portions on the insides of the legs These are welded to the cuff-ring and brought to the correct position to form the crotch, then welded from the top or the inside

All plates were partially shaped in the press, wrinkles measured from the photographs are either pressed or forged in The edges of the plates were heated with the torch and hammered flush before welding with the arc The cuffs were welded on last These are formed in two pieces having the lower edge turned in to a radius approximately 3/8-inch The cuff is then welded on the inside and hammered back to the trouser leg

Head—This of course, is by far the most interesting part of the construction A plate about three inches wide is cut and bent to the shape of the full-sized profile drawing, (See Fig 4), running from above the eyes back to the collar at the neck A collar is then made and welded to this strip at the correct angle Two plates were cut and shaped roughly, these extending from the inside of the collar to a point bounded at the top by a line running from the top of the ear to the center of the eyes and on the sides by the

Fig. 6. (left). Inner frame welded to top pedestal plate. Fig. 7. (right). Front view of inner frame of Churchill statue.

front of the ear and a line running straight down from the outside of the eyes. Two more plates were cut and forged to shape, connecting these face side-plates with the head profile strip. All joints were welded, we now had something more solid to build on.

The balance of the head was then plated in, rough-bending in the press, welding any part that would fit, then heating, hammering into shape, and finishing the welds. After the skull portion was finished, the face was built in. Two pieces were shaped for the roll under the chin, and welded to the collar to each other and to the face sideplates. The chin is one piece forged to shape and welded on, a deep crease between the chin and neck roll being formed by bending in the edges and welding on the inside.

Next the upper portion of the mouth extending below the nose and running down the creases below the cheeks, was bent into shape and welded on, at the sides of the mouth.

The chin and this latter piece do not run around to the face side-plate, it being more convenient to fill this in after these parts are in place. The lips are not worked upon until the entire face is assembled, as the facial expression is obtained from this point. Now the cheek-plates are formed and welded in, and these fill in the balance of the face, leaving holes for the nose and eyes. The nose is made in two pieces, one on each side, rough-shaped and welded to the cheeks, the unwelded seam down the center is then heated and hammered into shape and welded, a small bar being welded in to separate the nostrils. To obtain the correct shape, it was necessary to add a little metal in places. This was heated to a white heat and forged smooth.

The bulges below the eyes were put on next, then the curving piece between the eyes and forehead. Eyelids are small pieces welded into place on the corners of the outside and a shallow weld on the inside to make a deep crease just above the eye The eyes are small pieces of plate dished by hammering and welded into place on the inside. Eyebrows are easily made by welding on a curving bead.

The ears are easily made, although, they appear difficult and complicated. Fig. 9 shows a close-up of the head. A piece of plate is cut to shape allowing an extra half (½) an inch of material for bending to form the ridge on the outside, which extends down close to the lobe. The piece is heated at the area of the ear passage, and is dished deeply by hammering. The sides are bent out to form the outer ridge, then, using a small electrode, the ear detail is built in. By examining the ear of one of the students from time to time during this operation, very close detail was accomplished. The sides of the head were heated and dished to fit the dished portions of the ear cavities. The ears were then welded on the front and also at the back of the dished portion.

The lips were next built in, using a ⅜₂-inch electrode. The deep crease on the side of the mouth being forged in, completed the construction of the head except for the hair. All welds were ground smooth with a portable grinder.

First the hair was drawn on with chalk, running the lines in the direction the hair is worn. Stringer beads were then run side by side, starting at the front and running back, following the chalk lines, the hair being thin on top and thinning out to the bald spot on the crown. The sides being quite bushy, necessitated building out. A bare electrode $^5/_{32}$-inch in diameter was found the best for the formation of the hair.

It is the writer's opinion that this method produces realistic hair faster and easier than that produced by the conventional method of sculpture.

Fig. 8. Wavy hair made of stringer beads.

Almost any hair style can be quickly and easily formed. Waves are built up with plate and stringer beads are run over them. Fig. 8, "Man of Industry's" head, shows front waves with hair combed back. For deep waves the stringer beads are run far apart, or some may be missed out altogether, to obtain the correct effect. Parting in the hair may be formed by missing a bead or by starting the beads at the parting and running away from in which ever way the hair is worn. Grinding will take the tops off of the beads, leaving a sharp lined effect much the same as is usually used on the cut or chipped statue.

The finished head now had the bow tie welded on to the collar. It was then carefully set up on the top of the inner frame and welded.

Shirt—The shirt is made of a triangular piece of plate curved slightly; a band of mild steel was used to make the shirt seam. This was welded at the top and at the bottom underneath the coat. A shirt button was welded on through a hole in its center.

Coat—The front of the coat consisted of two plates, one on each side—the plates being lapped and welded from the inside. They are not lined up tightly, but, are allowed to gap here and there a little. Flat bars on edge tie the coat plates to the inner frame. The top portion of the back, (See Fig. 10), is of one piece, pressed to rough shape and then heated and the metal rounded at the armholes and shoulders. A piece of plate joins the back and front of the coat across the shoulders. Then the balance of the coat was

blocked in The lapels and collar were then made up, the edges rounded and welded on the inside and then hammered down. The sleeves are made of two pieces, the first part being the portion close to the body This was edge-welded on the inside, that being the easiest method, owing to the narrow width between the coast and sleeve at this part The outer part of the sleeve was made, but was not welded at this time as the hands must first be made up and welded on to the inside of the sleeves

Hands—Two of the well known Winston Churchill's characteristics were placed in the hands His ever present cigar, and his rather peculiar shaped hat The hands were made, using standard iron pipe. First a piece of three-inch pipe was heated and flattened to form the palm. The balance was split and a piece taken out The split portion was then heated, closed up, and forged to the shape of the wrist Small pieces were then shaped and welded to form the lower portion of the thumb One-inch pipe was used on the rest of the thumb This requires some building-up and hammering to obtain the correct shape The fingers are made of one inch and three-quarter inch pipe They were cut to size, then wedges were cut out to facilitate bending to the desired shape These were welded, and small pads built up on each side of the weld on the inside of the fingers to form the creases at the knuckles

Finger nails were made by grinding a low spot on the finger ends, and then fitting a piece of thin steel and welding with a small electrode The thumb was welded to the hand first, and then the cigar (or hat, whichever was the case) was welded to the thumb The rest of the fingers were carefully positioned and welded into place

The back of the hands and knuckles required extra metal to bring them to the desired shape This was easily built up with the arc By careful manipulation, the chords and irregularities of the hands were built in A little grinding and hammering completed this part of the job A short sleeve cuff

Fig. 9. Welding on shoulder plate.

was welded on to the wrist. Short brackets were then welded into the half-sleeves, to which the hands were welded, (See Fig. 11), these brackets holding the hands so that they come out in the center part of the sleeve. The outer half of the sleeve was then welded in place to complete this operation.

Six small sleeve buttons and three large coat buttons were turned in the lathe, holes drilled in the centers and then welded in place through the holes. All welding was now completed.

The job was then checked for accuracy of detail. A few creases were then added by heating the metal with a large oxy-acetylene torch and forming them, using specially shaped tools. All welds were then ground smooth with a portable grinder.

The finished statue was given a coat of metal primer followed by two coats of dull black paint to protect it from the elements and bring it to a uniform color.

Our efforts were not in vain, our first statue had been a sensation, this one was doubly so. Again the welding department held the feature position at the school exhibition and at the city's annual fair. The statue now stands at the intersection of the two main streets, the most prominent place in the city, (See Fig. 12).

Cost

Item	Amount
3/16 Mild steel plate—1050 lbs. @ 8¢	$ 84.00
1/4 inch plate—200 lbs. @ 8¢	16.00
3/8 plate—110 lbs. @ 8¢	8.80
3 inch tubing—95 lbs. @ 12¢	11.40
Shield arc electrodes—75 lbs. @ 17¢	12.75
Bare electrodes—7 lbs. @ 9¢	.63
Current for arc welder—82 hours @ 15¢	12.30
Oxygen for heating and cutting—1520 cubic ft. @	22.80
Acetylene for heating and cutting—1125 cubic ft. @	22.80
Labour for welder—180 hours @ $1.25	225.00
Labour for helper—180 hours @ 50¢	90.00
Paint—3 quarts	7.05
Buttons turning in Lathe—2 hours @ $1.50	3.00
Photographs	2.80
Total Cost	$519.33

The construction of this statue was carried on by a class of ten boys, ranging in age from 16 to 20 years. As in the case of the other statue, none of these had any experience, nor could claim any talent in sculpture work.

Little actual skill in sculpture was found necessary to fabricate the statues. It could be classed more as an engineering project, rather than an art. Scale, spirit level, and plumb-bob were relied upon. Measurements were frequently taken from a plumbed straight-edge erected at the back or the front of the statue. Erection lines were used on the pictures, these lines correspond to the plumbed straight edge. Measurements were easily made, locating the height on the line and measuring in from that point. By this method, measurements were converted from the pictures to the statue.

An arc welder of average ability can do this class of work. He must, of course, have patience and some imagination, and be able to measure correctly and accurately. With some small grinding equipment, such as used in die

Fig. 10. Construction of coat.

making, better results than were accomplished by us could be easily attained This work could be developed by experience into some magnificent works of art

It is true, of course, that iron or steel, (with the exception of a few alloys) has not the lasting qualities of bronze or stone, unless it is painted every few years However, this rusting away of steel is being controlled by the use of new alloys, so that durable statues can be built of this material.

There are a number of processes also, that can be used to protect the metal, some of them produce a finish of pleasing appearance as well

The metalizing process could be very successfully utilized to put a protecting coat on to this type of statue. This process for finishing has wonderful possibilities, in it, the metal being coated is roughened by sand blasting, then it is sprayed with molten metal, much the same as paint spraying. A good mechanical bond is accomplished between the sprayed metal and the work. Almost all metals may be applied by this process. By first assembling a steel statue by arc welding then spraying with a suitable corrosion resistant metal, a large number of colors or color combinations could be obtained; various bronzes and brasses, copper aluminum, stainless steel, zinc, lead and many others may be combined together to produce both attractive and durable combinations impossible to obtain by any other method of sculpture.

The conventional methods of sculpture are limited to certain styles of construction. In the chipping or rubbing out of stone, it is impractical to produce thin or complicated sections due to the brittleness of the materials being used. Stone has a definite grain structure, and behaves somewhat the same as wood in that regard—that is, being very weak and brittle across the grain, consequently making it difficult to carve small protruding parts There is always danger of chipping or breaking of parts in moving a finished statue. With this to contend with, the design does not altogether lend itself to lifelike production; clothes worn by a statue cannot be made to appear apart from the figure, but must be a part of the general outline, giving an impression of thickness.

In the modelling of plastic material, certain liberties may be taken over the previous method, however, as the finished model must be used as a pat-
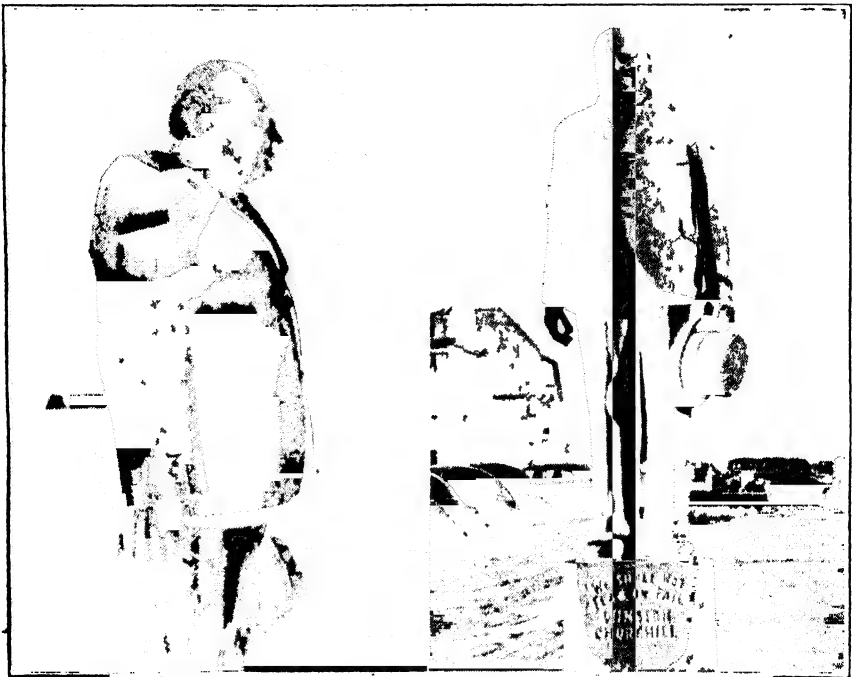
Fig. 11, (left). Right hand welded to bracket in sleeve. Fig. 12, (right). The all welded steel statue of Winston Churchill.

tern for casting, the work must be executed with this in mind. This cuts down to a great extent the freedom that could otherwise be used in the finished sculpture.

The arc welded steel sculpture eliminates all of the difficulties encountered in the previous sculpture methods. Greater freedom of design may be employed, complicated parts may be made separately and assembled to the statue later. There is no brittleness or weakness in any part, complicated protruding parts may be put on with no danger of breaking off. If errors are made they can be easily corrected, by cutting out the part with a cutting torch and rebuilding or plating the part to the correct shape—an impossible thing to do in stone cutting. Casting procedure is entirely eliminated so that pattern design can be ignored and lifelike appearance attained. The arc welded statue is easily and quickly built, not requiring the skill and care so necessary in successful sculpture of clay or stone.

Comparison of price between the arc welded procedure and the other methods of production is a difficult thing to do. The author has not had the opportunity to study costs as applied to methods, other than arc welding. A number of small statues have been erected in the district in the past few years —these in the form of memorials. These statues were all imported from Italy, a source now closed for the duration of the war. The price of these statues range from $600 to $1200. They are in the form of commercial shapes only. For example—an angel, Christ, a soldier or a child.

The cost of a statue of a definite person usually runs quite high. Prices quoted for a life size statue range between three and four thousand dollars for a stone figure, and somewhat higher for a bronze figure. The arc welded steel statue easily competes with these prices.

This is not, of course, in the general run of arc welding but with its marked advantages, ease of construction, and comparative low cost, it opens up a field that has never been as broad as it is at the present time. With a world conflict in progress, new heroes, great men and women are in the making All are worthy subjects for the sculptor. Memorials for soldiers, airmen, sailors and marines will soon be in great demand. Every city, town or village of any size will erect a suitable memorial to the boys who went away to fight.

Large sums of money are raised, usually by public subscription, for this purpose. A large volume of profitable business could be built up for arc welders interested in the art of welding, developed into welded art.

SECTION VI
Furniture and Fixtures

Chapter I—Arc Welding of Plated Tubular Furniture

By ERNEST REISS,
General Manager and Partner, The Art Chrome Company of America, Boston, Mass.

Ernest Reiss

Subject Matter: Detailed descriptions of bending, plating and welding of various pieces of chrome-plated tubular furniture, including a kitchen or soda fountain stool, saving in cost $1.11 or 30 per cent, a kitchen chair, a breakfast table, a combination stool and step ladder and a large upholstered chair are given. The welds are kept on the under side as much as possible and are painted with aluminum paint to cover the "burn" in the plating.

Any discussion of arc welding in relation to furniture, is itself a discussion of the philosophical trend of twentieth century man. Every age, every era, has a tempo, a vision, a scale of values, that finds expression in the design of the useful things that man needs. In the design of contemporary furniture architects and designers have turned to the new materials from which to mold their masterpieces. These new plastic materials have significantly been those that mark our era—steel—plastics—glass. Steel having played the most significant part in our history and life was the material first used for furniture by those pioneer designers Marcel Breuer and Walter Gropius, as far back as the Bauhaus in Germany before World War I.

Steel tubing lent itself readily to the functional problem. It had strength, solid line, and dynamic possibilities. It was a material which could be either painted, or better still, given a lustrous hard lasting finish by a truly new process called chromium plating. It was a material that was plentiful, inexpensive, and easy to fabricate. It was a material which would blend and cooperate with the scheme of the new architecture which called for simplicity, freedom, and the expression of man's creative genius.

Tubular steel furniture, thus evolved, had its beginning in Europe and logically came to this country to be copied and improved on by American methods. The early designers gave us the initial impetus and the original idea of functionalism. We gave to tubular furniture popularity and mass production methods. The resulting economy made it an item that anyone could purchase. It became possible for restaurants, shoe stores, beauty parlors, yes, even bowling alleys to have chrome furniture.
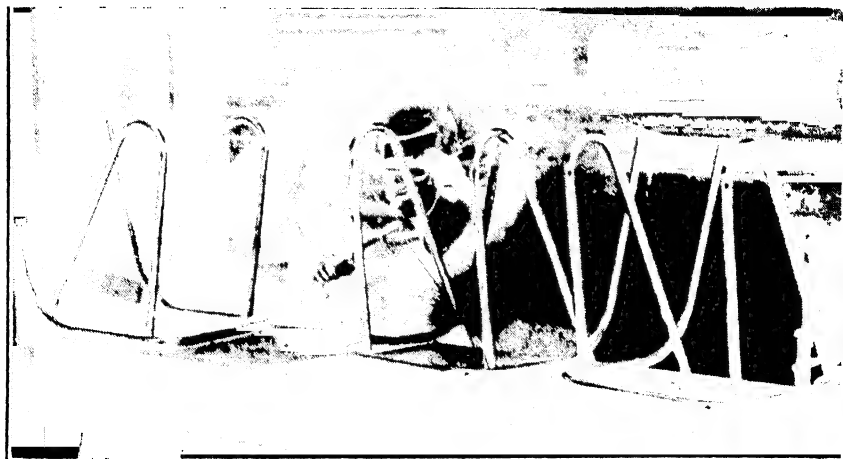
Fig. 1. Arc welding plated tubular furniture.

Arc welding, (See Fig. 1), is an American contribution to the popularity of chrome furniture. We are proud that our company has been one of the pioneers in arc welded construction of chrome tubular furniture.

Arc welding has made possible:

1. cheaper methods of construction
2. improved appearance
3. faster construction
4. added strength
5. new designs impossible or too costly to manufacture in any other way

It is the purpose of this paper to deal with these five advantages of arc welded furniture as we applied them to items in our own plant.

It is not the purpose of this paper to deal with the problem of efficient management of a chrome metal furniture factory. Nor will we deal with costs and methods of cost estimating, except as a matter of comparison between old and new methods. These factors are subjects in themselves and the same broad principles that apply to the management and cost accounting of any successful business apply here.

It is my purpose to show and explain, as completely as I can, the improvements and new discoveries that we have made in our own plant, hoping that perhaps they may be of benefit and encouragement for the future to a metal furniture industry striving hard to find its place in a world at war.

The largest single cost on an article of chrome furniture is the plating itself. This is so, because chrome plating involves many processes, most of them involving manual labor. The frames, after being formed and fabricated to desired shapes, must be polished, washed in alkali cleaner to remove grease and dirt, rinsed, dipped in acid, rinsed again—once more in alkali cleaner, rinsed and placed in the copper tank. After the copper plate the frame is rinsed in cold and then hot water and buffed. It is again put in the alkali cleaner, rinsed, dipped in acid, rinsed, and into the nickel tank. Once again cold and hot water rinse after plating and once again buffed. Then it is put into the chrome tank and finally rinsed in cold, and then hot water. There is also a newer process using hot nickel which eliminates the copper plating. Tanks are limited in size for practical purposes. The bulkier the item, the

fewer pieces in a tank at one time. Since it requires 30 minutes in the nickel tank alone, progress of work depends on quantity in tanks at one time. All these factors influence final cost.

To produce furniture at the lowest cost we began with the following basic facts.

1. Simple, "one plane" bends were cheapest to fabricate both from the bending as well as the plating angle. Many more pieces could fit into the plating tanks if they were composed of simple one plane bends.

2. Welds and flanges represent additional costs in buffing as well as grinding before buffing.

3. Complex bends and welded pieces were sometimes even impossible to chrome as the plating would not "throw" into the crevices.

Experiments with arc welding showed us that with the proper heat 60-70 amps and 3/32-inch coated-rod chrome plated tubing could be welded securely, and the "burn" confined to a distance of not more than 1/2 inch. When the weld was cleaned and painted with aluminum paint, the joint was not unsightly and particularly good when welded on the underside or where covered with some other part of the article of furniture.

The first item we tried electric welding on, was a bar stool which we sold for use in kitchens, playrooms, soda fountains, and bars. In this particular case, electric welding was our last hope. The stool which I shall presently describe was giving us a great deal of trouble. It was originally constructed of 4 pieces of 1-inch ground bedstead tubing bent to form the legs of the stool, and one piece of the same material bent to form a 12-inch square and which served as the footrail. A piece of 1-inch x 1/8-inch cold rolled steel, rolled into a circle served as an inside support and was believed to be of some decorative value. The square ring was bolted around the legs, the cold rolled steel was bolted inside near the top.

Both of these items were acetylene welded and ground so that they formed each a continuous piece. All six pieces were then chrome plated before assembling.

The legs were bent over at right angles to support the top. This top was a round upholstered unit made of wood and upholstered with leatherette. It was screwed to the legs by wood screws and acted as a third support to hold the legs together, (See Fig. 2).
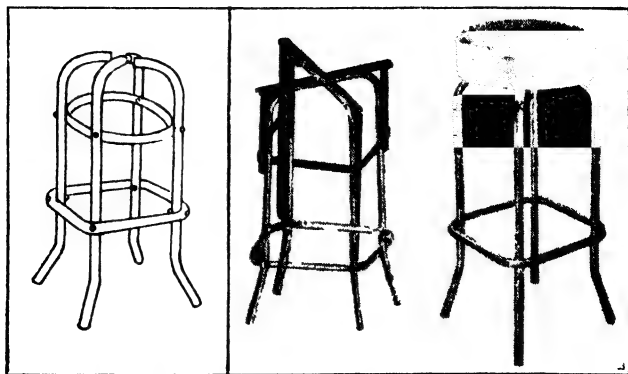
Fig. 2, (left). Sketch of stool frame. Fig. 3, (center). Legs and foot rail in special jig for welding. Fig. 4, (right). The finished stool.

But somehow these three supports refused to hold the stool together. Whenever a nut worked loose it was only a short time until the rest of the stool disintegrated. It was proving costly to replace them and we turned finally to electric welding.

After some experimenting we found that a 3/32-inch coated welding rod would weld chrome plated tubing together with a minimum of "burn."

The four separate legs were first welded together at the top by placing a 4-inch square steel plate on them and welding the legs to it. This first needed simplification.

Our first step then was to change over from 4 legs to one loop which served for 2 legs, and 2 single legs. These three pieces and the same square tubular footrail used on the previous stool, were chrome plated. The legs and footrail were then placed upside down in a special steel jig, (See Fig. 3), and the two single legs welded at their top end to the double leg.

In this same position, upside down, we electric welded the foot ring to the legs from the under side.

When we turned the stool right side up the welds could not be seen on the foot ring, and when we put the seat on the top, it covered the weld joining the legs together. We then found that we did not need the inside ring as our stool was now stronger than we ever needed it to be (See Fig. 4).

The welds were cleaned with steel wool and painted with aluminum paint to protect them against rust.

We discovered that we had unconsciously removed a stocking hazard by eliminating all screws from the foot ring.

When we began to figure costs and time we found the following:

	Old Method	New Method
14′ 4″ Bedstead ground tubing	.70	.70
Inside ring including plating	.56	
Plating	.65	.65
Upholstered seat	.58	.58
Glides	.07	.07
Screws, cap nuts and washers	.25	.01
Cut tubing	.05	.04
Bend	.12	.12
Drill	.12	.02
Weld tubular ring	.10	.10
Assembly	.50	.05
Weld, clean and paint		.25
	$3.70	$2.59
	2.59	
Savings	$1.11	or 30%

Old Method		New Method
4 legs	8 cap nuts	2 legs
1 tubular ring	8 1/4-20 screws	1 double leg
1 flat ring	8 lock washers	1 tubular ring

The other advantages we obtained were:

1. Added strength and permanent construction
2. Absence of screws which might loosen or tear clothes
3. Less parts
4. Less time to manufacture
5. Lower costs of manufacture

Welding time in the jig was 10 minutes at 65 amps. Two $^{5}/_{32}$-inch coated rods were consumed.

With this item so satisfactorily built by electric welding, we turned with enthusiasm to new fields. We found it possible to add two completely new chairs to our line. One was a better construction of a highly competitive number, the other a brand new chair, which besides possessing ease of manufacture, is to our mind one of the most attractive chairs on the market.

The first chair was a four legged conventional chrome tubular kitchen chair. It was made entirely of $^{7}/_{8}$-inch tubing and contained altogether 11 feet 2 inches of tubing. It was made of four pieces of ground tubing, and one additional piece for a stretcher. The bending was simplicity itself, two pieces with two bends each, and two pieces with one bend, (See Fig. 5).
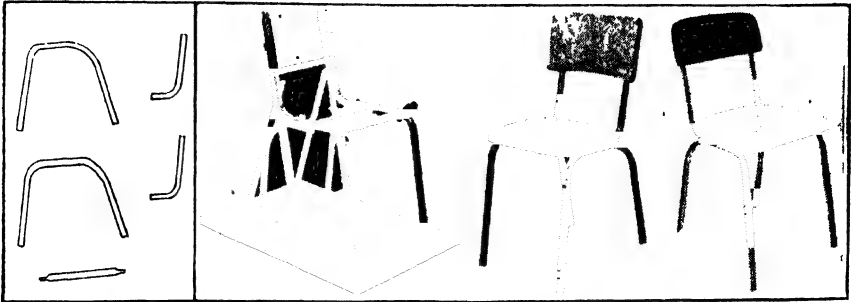
Fig. 5, (left). Details of bending the chair frame. Fig. 6, (center). Chair frame in arc welded jig. Fig. 7, (right). Completed chair with cushioned seat and back.
Fig. 8. Chair adapted for Navy contract.

We used our scrap (waste tubing) for the stretcher, flattening both ends in a punch press. The four bent pieces were plated, placed in a specially constructed arc welded jig, (See Fig. 6), and welded in one operation with no special skill needed. The backs were welded to the loop forming the legs, and then each leg was welded to the stretcher. The welds were cleaned and painted. The stretcher and legs were drilled to attach the wooden upholstered seat. The back supports were drilled to hold the upholstered back. When back and seat were screwed into place the chair had ample strength for its use (See Fig. 7).

This chair has been made, similar in appearance, by other manufacturers without electric welding, but with half the strength and always with more tubing, off plane bends, and higher manufacturing, plating, and assembly costs. Our chair, with the addition of another stretcher, and with a wood saddle seat and wood back, was approved for a Navy contract, (See Fig. 8).

The specifications on this chair for this purpose were as follows:

Design—Chair shall be of the usual four leg type in appearance except that it shall be constructed of a frame of chromium plated steel tubing with a wood seat and back.

Frame—Tubing shall be approximately 1-inch, 14-gauge cold rolled steel tubing free from pits and fissures; commonly known as O. D. 14. No other will be acceptable.

The tubing shall be electro-plated with at least three platings as follows: Heavy copper deposit of no less than .0003 to .0005 inch after buffing and polishing. Heavy nickel deposit of no less than .001 to .002 after polishing. A final deposit of high quality chromium of no less than .00002 inch or more.

Frame Construction—The chair frame shall be composed of a base frame to form the legs and a back frame supporting the wood back. The base frame shall be formed of two inverted "U" shaped lengths of steel tubing. These are to be securely welded together by means of a steel tube which shall run in parallel with the seat and at right angles to the "U" shaped pieces it joins together. All welds are to be complete. The ends of the "U" shaped tubes shall be the feet of the chair. These shall be equipped with fitted chromium plated steel glides which shall act to prevent the chair foot from marring the floor.

The back frame shall be composed of two supports each to be 18 inches in length. These supports shall be of chromium plated steel tubing. Each support shall be securely welded to the rear portion of the upper rear leg frame. The upper ends of the back supports shall be fitted with a permanent chromium plated steel cap.

Seat—The seat shall be of an accepted hardwood, shape to be of the commonly known saddle type. It shall be securely fastened to the frame by means of four round head blued #10 wood screws, which shall not be exposed on the surface of the seat itself.

Back—The back shall be of an accepted hardwood material postured or curved to fit the body. It shall be securely fastened to the back frame by means of four flat head chromium plated self tapping ½-inch diameter screws. They shall be counter-sunk into the face of the wood back. No screws shall be visible from the rear of the chair.

Dimensions—

Seat	15"x15"
Back	15"x9½" high
Height to top of seat	18½"
Height to top of back	32½"
Floor area	14½"x18½"

The time required for welding this chair in our jig was 5 minutes. The amperage was 70 amperes and one 3/32-inch coated welding rod was consumed.

The new chair made possible by arc welding was our #M6M kitchen chair. This was promoted with our KTME kitchen table. The unit was made to meet the demand for a better chair and table combination. The problem was to design a table that would be a little different in design; extra strong in construction, and at the same time to design a chair that would match and have the same qualifications.
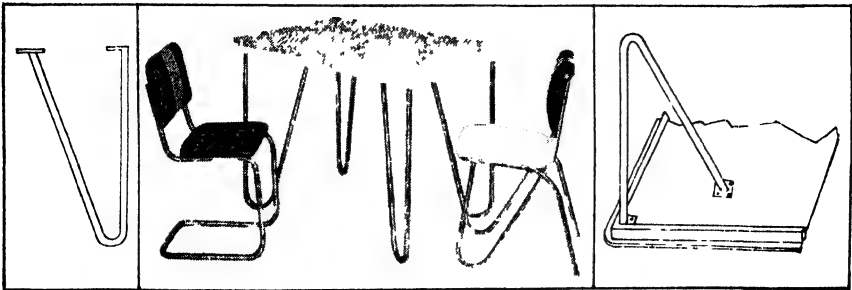
Fig. 9, (left). Development of table leg. Fig. 10, (center). Welded chairs and table. Fig. 11, (right). Connection of leg and table top.

After quite a number of experiments and many hours of sketching and testing, we developed a table leg, (See Fig. 9), and a chair to match, (See Fig. 10). The table leg was of the "hairpin" variety, a term common to the breakfast table trade, only instead of connecting to the table by attachment to the skirt, our leg had one end attached to the inner corner behind the skirt and diagonally in from the corner, (See Fig. 11). The leg was made of 7/8-inch tubing bent in a V shape, chrome plated, and the flanges 1/4 inch by 4 inches square were electric welded one to each end, the welds and flanges painted with aluminum paint. The skirt hid the flanges and welds. The table was of the extending type with removable center leaf. The method of connecting legs with the ends diagonally toward the center gave the table a rigidity not obtainable in the common type of extending table. The legs took the drag of the opening and closing of the table without any vibration such
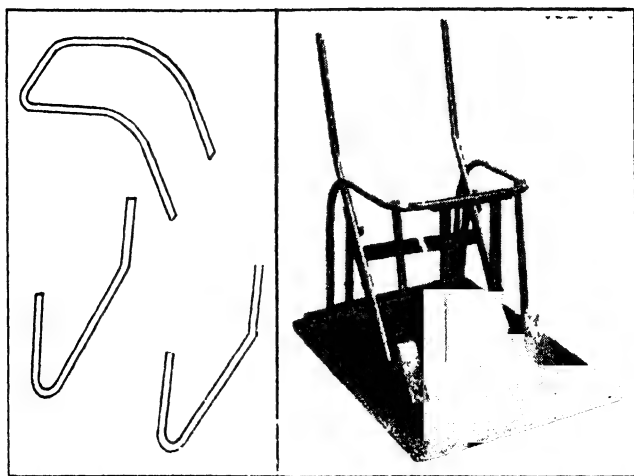
Fig. 12, (left). Three pieces of chair frame tubing. Fig. 13, (right). Chair parts in jig.

as was evident in the single leg or corner attaching style. The loop of the leg, being on the floor, eliminated the necessity of plugging the ends or adding glides. Subsequent reports indicated that this type of leg was exceedingly kind to floors and linoleum.

The chair was made of three pieces of 3/4-inch tubing, two pieces each forming one front leg and back support, and one piece forming the seat support and two back legs, (See Fig. 12).

The three pieces were placed in a jig, (See Fig. 13), after being chrome plated separately and welded together by four electric arc welds. Aluminum paint covered the welds. The upholstered seat covered the two front welds and the two back welds were not particularly noticeable. The front legs matched the table legs perfectly and were attractive as well as functional.

This chair can only be built by electric welding as there is no other method by which the component parts may be joined with sufficient strength to keep them together. It could not be joined by acetylene welding, since the cost of chrome plating would be prohibitive as the chair must first be acetylene welded and then plated.

The time required for welding was five minutes. Two 3/32-inch coated rods were used with the amperage at 65.

Another kitchen item was a combination work stool and step ladder. Cost of manufacture was of prime importance as this ladder had to compete with inexpensive wood ladders. It was necessary to use the minimum of tubing, simplest of bends, cheapest method of construction, and be composed of parts least expensive to chrome plate.

We designed the following stool:

Two pieces of ⅞-inch tubing 56¼ inches long were bent in a sort of "U" and near one end of each a ½-inch hole was drilled through one side only. One piece of scrap tubing 10 inches long was flattened at both ends and served as a stretcher. Four pieces of angle iron 3 inches long were cut and two #8 holes drilled on one side. A piece of ½-inch tubing was cut 10¾ inches long. The two "U's" and the ½-inch tubing alone were chrome plated, (See Fig. 14).
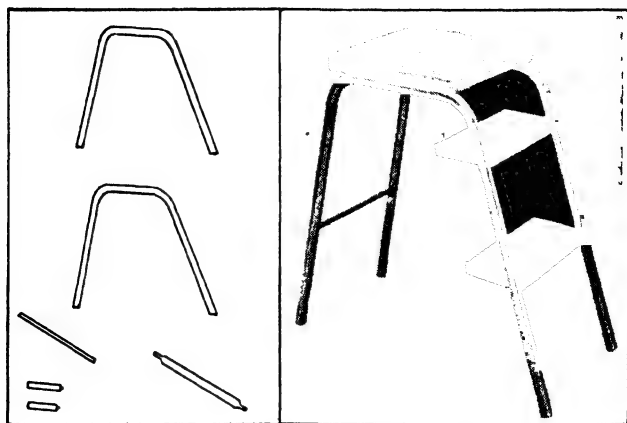
Fig. 14, (left). Parts for stool. Fig. 15, (right). The arc welded stool.

The two "U's" were then set in a jig, legs up, the two ½-inch holes facing each other. The ½-inch piece of tubing was placed, one end in each of the holes so provided. A small electric weld was then made joining the ½-inch tube to the ⅞-inch "U's". The stretcher bar was next placed in the middle of the bottom of the "U" and welded to the "U", the flattened ends making it possible to weld without building up around the tubing. The angle irons were then welded in predetermined positions on the other legs of the "U". Here too particular care was taken to keep the burn as small as possible and yet provide adequate strength to the joint. All welds were cleaned and carefully painted with aluminum paint. The stretcher and the ½-inch rod served as supporting members to hold the stool together and keep it rigid. The stretcher also served to hold the upholstered seat while the ½-inch rod served as a heel rest when one sat on the seat and used the item as a work stool. The angle irons held the ladder steps. They were made of plywood "5 ply", and covered on the front edge and top with corregated rubber matting. They fitted into the angle iron and were screwed to it by wood screws.

Besides being attractive and serving a dual purpose in the kitchen, this combination stool and step ladder is one that does not lose strength with time, as do the wooden ones when rails loosen, wood splinters, and glue dries out. It will always be a safe item, never a hazard. (See Fig. 15).

The actual cost on this item exclusive of overhead and packing costs is as follows:

Tubing 7/8"	$ .44
Rod 1/2"	.03
Stretcher and flattening rods	.05
Angles	.10
Wood	.09
Rubber	.07
Glides	.07
Seat	.33
Plating	.50
Screws	.05
Glue (for rubber)	.01
Bending	.05
Drilling	.06
Cutting	.08
Welding including material	.25
Assemble	.19
Total—labor and material	$2.37

The next interesting chair we developed was our #JM.

A piece of 1-inch tubing was bent to form the front member, somewhat in the form of the letter C with a short reversed bend in the back to raise the middle section of the C off the floor and form two points of suspension. Two of these pieces were bent for one chair. To these was welded one shorter length with a slight bend in the middle. This formed the back support and the back leg. The bend in this piece gives the back its required tilt. The welded joints were polished smooth on a portable sanding disk with No. 36 grit, resin bonded disks. Both pieces were then plated. In addition we cut three short rods 1/4-inch in diameter 22½ inches long, one 5/16-inch rod 23 inches in length, and one 5/16-inch rod 21¾ inches long. These pieces were also chrome plated. The two 5/16-inch long pieces were the seat support,
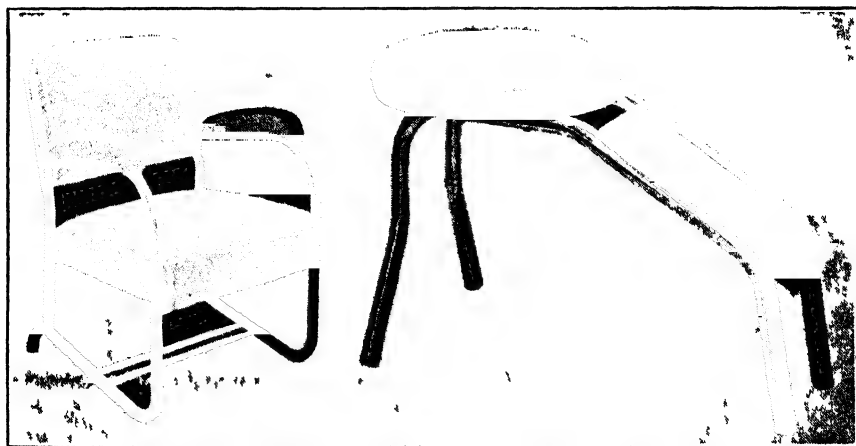
Fig. 16, (left). Chair adaptable to uneven floors. Fig. 17, (right). Chrome plated shoe-fitting stool.

and holes were drilled on the inside of the two arms on each end through one side of the tubing only to contain the ends of these rods. Three holes were also drilled in the bottom part of the arms through one side of the tubing only to accommodate the three 1/4-inch rods. When all the rods were set in place they held the two arms in an upright position. All that was necessary was to electric weld (on the under side) these rods to the arms. It was necessary to use care and thoroughly test these welds for strength. Aluminum paint covered the burn, and when the chair was set right side up, the wood upholstered seat placed on top of the 5/16-inch supporting rods, no weld was visible. The longer 5/16-inch rod was used in front to give the chair a taper toward the back for the sake of better appearance.

The chair possesses unusual strength from its all welded construction and does not depend on its upholstered sections to hold it together. It eliminates bolts, tapping operations and countersinking, and is thus cheaper in construction as well as easy to assemble. Assembly is done in an electric welded jig in 10 minutes as against an estimated time of 60 minutes if the chair were
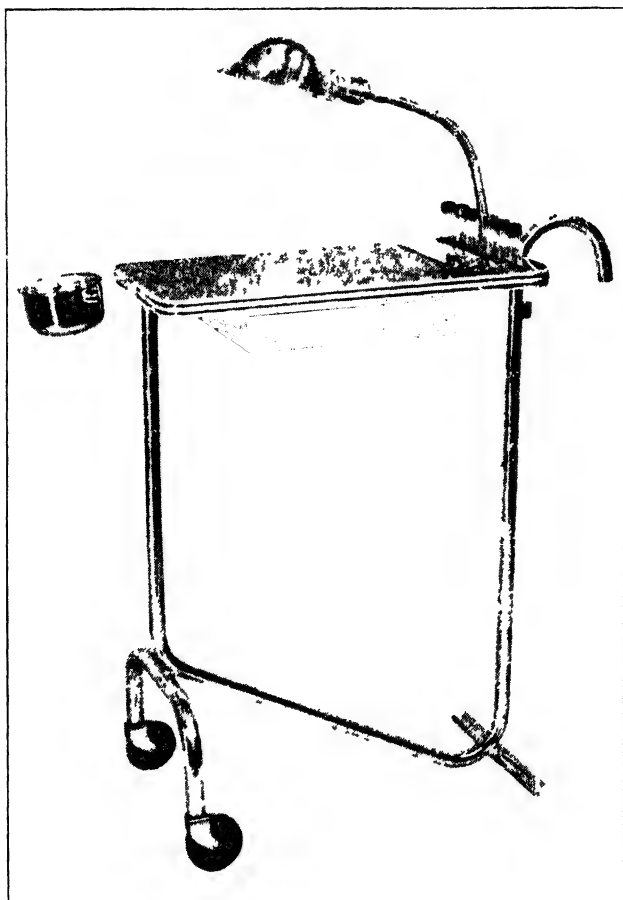
Fig. 18. Manicure table.

of a bolted construction. Appearance is enhanced by the absence of unsightly screws and a stocking hazard is eliminated.

The design of the arms and legs makes it possible to use this chair on uneven floors since there are four points of contact instead of two long surfaces were the tubing flat on the floor without the offset, (See Fig. 16).

One $\frac{3}{32}$-inch coated rod only, was used on the entire job with the amperage at 70 amperes.

This application of arc welding to metal parts already plated, is not limited in our plant to household furniture, but since the subject matter of this paper is limited, we have not mentioned how we use this process to fabricate the many commercial items we manufacture. For example, we make a chrome plated shoe fitting stool, (See Fig. 17), which is purely functional and impossible to manufacture at twice the cost except by arc welding. We make a manicure table for beauty parlors, (See Fig. 18), a chrome shoe chair unit for shoe stores, chrome booths for restaurants, chrome swivel chairs for offices, and other items all with this same technique.

It might be well to mention here that we have found in our experience that the designer alone cannot create nor solve the problems merely by sketching his ideas on paper. The cost of performing the various operations is a major consideration, and the possibility and feasibility others. The designer must know costs or work with the man who does. He must know methods of construction or work with the foreman of the department. And, if it be arc welding that he is looking to for the solution, he must work with the man with the mask, trying new ways, experimenting, testing, keeping costs. Only in this manner, have we found the way to create and improve.

Chapter II—Wrought Iron Furniture Manufacturing

By Joseph H. Woodard,

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Joseph H. Woodard

Subject Matter: Many of the parts of wrought iron furniture are formed in a punch press. Trouble was experienced by the breaking of dies. An arc welded die was made to replace the former cast iron die at a saving of $2.42 per die or 30 per cent. This represented an annual saving to the company of $608.
An improved floor glide for furniture legs involving welding was developed representing a saving of 23 per cent on this item or $1,125 per annum.
A method of welding brass ornamentation to the wrought iron was developed which represented a saving in this item of 43 per cent or $1,300 per annum.

Since 1934 it has been the author's pleasure to be joint owner and plant manager of a concern manufacturing a large line of wrought iron furniture. This line totaled in 1941, 150 different catalogued items, such as all variations of seating pieces—side chairs, arm chairs, gliders, benches; tables—dining, console, lamp, coffee, end table, and nest of tables. In addition, there are beds, mirrors, tea wagons, plant stands, wall brackets, bookshelves, magazine racks, etc. The development of such a comprehensive line was the natural growth of a moderately successful business, covering the six years prior to 1940.

During these years the application of arc welding became such an integral part of our manufacturing process, that as regards the problem of joining two pieces of metal together, we found ourselves thinking in terms of this method. By way of explanation, all the metal parts that form a unit of our furniture are joined by either arc or spot welding, no screws, bolts, clips, or other means being used. Undoubtedly most, if not all, of the welds could be accomplished by the acetylene method. The basic advantages of lower material and labor costs that arc welding enjoys over acetylene, however, were so apparent to us at the outset (1934), that we did not use then, or have since, acetylene equipment.

One basic characteristic of all our furniture is its hand forged appearance. The term "wrought iron" not used technically implies hand craftsmanship, or at least a hand-made appearance. It is, therefore, our desire to produce with modern methods and technique items of beauty and to emulate in texture the works of old ironsmiths.

Some of our operations are performed in much the same manner as in years past. This is true in the case of small forgings, where, because of the large number of bar sizes and the various number of forged shapes involved, it would be impractical to invest in necessary dies to do the work under power pressure. We are still using the time established method of fire heating and hand forging on an anvil. As compared with old methods, the assembly technique has improved most, and this chiefly because of the developments of arc welding.

By 1940 our welding operators had achieved a surprisingly high degree of skill and efficiency. Because of their ability to not only weld, but to "fill in", weave, and to "taper out", the appearance and quality of the arc welded joints are difficult to differentiate from those of slower methods such as fire and acetylene. While the problem of warpage must always be considered, arc welding minimizes this condition because of the concentration of heat applied.

All of our welding is on light metal, often as light as 20 gauge sheets and 1/8-inch diameter wires. In addition, the welds are very short in length, never more than 1 inch. This type of welding is generally referred to as "tack welding", except that in our case welds are final, not later supplemented with additional runs. It is most important, therefore, that all joints be well fused, with a minimum of excess deposit and splatter. We use three different electrode sizes, namely, 3/32-inch, 1/8-inch, and 5/32-inch.

Inasmuch as all our designing is done by members within our own organization, many of the welding problems can be solved in advance. Whenever possible, the welds are placed in hidden locations; with a table, for instance, on the underneath side; on a chair, underneath and on the back sides. Following this practice eliminates much grinding and cleaning. Welding jigs are made up so that practically all final welding assembly work is done with the article of furniture in an upside down position. The work is positioned as to provide horizontal or vertical welding. Overhead is always avoided wherever possible because of the loss of time, material, and the relatively poorer quality of joint. It is interesting to note that in cases where it is of prime importance to obtain a smooth flush bead, it is easier to weld with the work in a vertical position, welding down, than horizontal.

Good welding jigs are most essential. After a perfect sample is once built, it is a simple matter to weld up around it a separate jig framework to be used subsequently in holding in perfect alignment during the welding process the various pieces of a complete unit. The jig should be built to allow the completed welded unit to be easily removed. Stop pins, hold down clamps, and other ideas can be worked out to allow the operator free use of his hands. Welding jigs increase production, eliminate warpage, and insure accurate work. Jigs often present an opportunity to protect work adjacent to welds from splatter by attaching a piece of sheet metal thereabout. With our own welding equipment, jigs are inexpensive to build and often pay for themselves on a production run of as small as ten pieces.

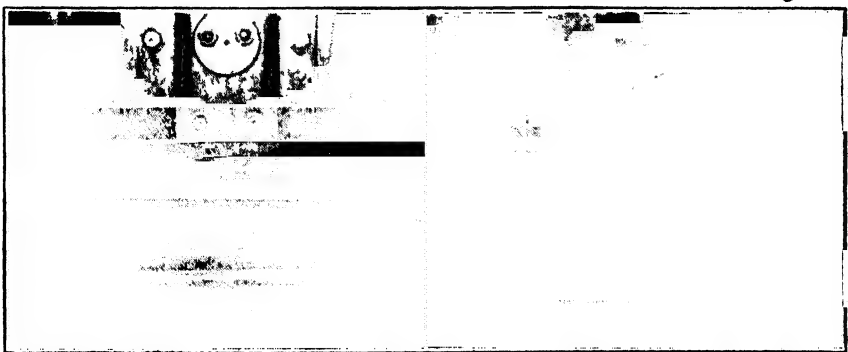



Fig. 1, (left). Cast iron die for forming angle iron. Fig. 2, (right). Welded steel die for forming angle iron.

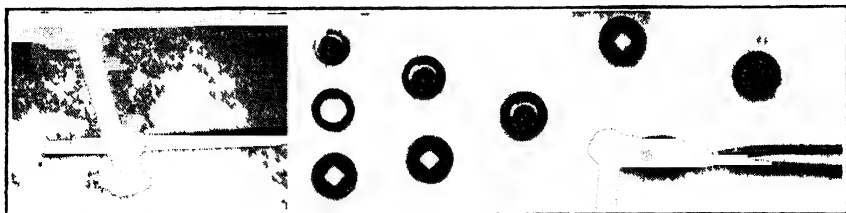



Fig. 3, (left). Original single-punched disc. Fig. 4, (center). Improved furniture glide. Fig. 5, (right). Tool used in arc welding cup to leg.

So far I have merely related our general application of arc welding prior to 1940 Since then we have made three improvements to our products or manufacturing methods, all of which were made possible because of the arc welding process These developments are all embodied in the production of our 755-A chair which is selected by the author as a typical unit to serve as the subject The following discussion, all of which pertains to the 755-A chair, falls into the following headings

1 Arc welded steel forming dies for punch presses
2 Development of set in rubber stainless steel floor glide—arc welded to steel furniture leg
3 Brazing by arc welding brass ornamental castings to steel furniture frames

I

Arc Welded Steel Forming Dies for Punch Presses—Many of the forming operations on our bar stock are performed on punch presses We had used cast iron dies, moulded from wood patterns and machined to size, Fig 1 These dies are subjected to severe strains and were continually breaking We found it impractical to repair the breaks by any means, even arc welding, and broken dies had to be replaced Of course, solid steel dies completely machined would have overcome our breakage problem, but the machining expense would have made the cost excessive

In early 1941, because of a broken die which was urgently needed, we decided to replace it by welding up a steel die using short pieces of our scrap bar sections properly formed and welded into a solid unit, Fig 2 To our great satisfaction, this die proved to be far superior to those of cast iron, and since then all such dies have been made in this manner As compared with the cast iron dies, the steel ones are practically unbreakable, are lighter, cost less, and have the advantage of being easily reinforced at wearing spots by welding over such places a bead of tool steel electrode and grinding smooth.

The production of such dies is as follows After the pieces to be made into the die have been formed, we have found it good practice to place them together in their relative positions in the punch press, and perform the welding while they are held tightly between the press ram and bed. By allowing the dies to cool in this position before removing will eliminate warpage and will insure the die surfaces of being parallel, making unnecessary any machining Tapped holes for bolting the dies to press may be eliminated in some cases by welding nuts to the sides of dies If hold down clamps are used, lugs may be welded to dies Vulnerable surfaces of the press may be protected from welding splatter by covering with a thin sheet of metal

A comparative cost estimate of two typical dies follows, (See Figs. 1 and 2).

Comparative Cost Table of Cast Iron and Welded Steel Dies

Cast Iron

Item	Cost
Material:	
Wood pattern band sawn	$1.50
Cast iron, 30 lbs. @ 6¢ (includes foundry labor)	1.80
Labor:	
Machining, including tapped holes 5 hours @ 1.00	5.00
	$8.30

Steel

Item	Cost
Material:	
20 lbs. hot rolled steel @ 3½¢ lb.	.70
1 lb. coated electrode	.085
Labor:	
Cutting and forming, including tapped holes 3 hours @ 1.00	3.00
Welding, 2 hrs. @ 1.00	2.00
Effected savings 30%.	$5.785

The total annual savings to our company as a result of this changed die construction can be estimated as follows: During the year 1939 a total of $1,520 was paid for cast iron dies. If we had taken advantage of the welded die construction during this year, a savings of 30 per cent of $1,520, or $456 would have been effected. This estimated savings does not take into consideration breakage; no plant figures are available on this expense but it is the author's opinion that the elimination of breakage has effected at least an additional 10 per cent savings for a total 40 per cent of $1,520 or $608.

II

Improved Floor Glide on Furniture Legs—Previous to 1940 we had been welding around steel disc to the foot ends of chairs and table legs to serve as a floor glide. This was a cup-shaped stamping with a hole punched in it slightly larger than the size of the leg to which it was attached. The disc was slipped over the end of the leg and welded from the bottom side, (See Fig. 3). This glide was satisfactory when the furniture was used on a lawn as it did not allow the legs to push down into the ground. It was not, however, satisfactory for use on fine terraces, linoleum, or hardwood floors, as its sharp edges had a tendency to mar the surface. It would cut into rugs, making difficult the gliding of the article across the floor. We experimented with rubber crutch tips, and while they protected the flooring, they did not allow the furniture to be easily moved. Some other means had to be developed.

Standard furniture glides for legs of wood or steel tubing are on the market, but none are designed for use on solid bar stock. The ideal type of furniture glide, particularly for steel furniture, is one that embodies a rubber cushion between the metal glide and furniture leg. The rubber cushion greatly overcomes the rigidity always objectionable with steel furniture. We proceeded to develop a rubber cushioned glide that would meet our own re-

quirements of being readily attached to solid bar legs approaching the floor at many different angles.

The new glides, (See Fig. 4), are an assembly of three parts. One, a cup shaped stamping of polished stainless steel serves as the bearing surface of the glide. This part is so rounded and polished as to allow the easy moving of the furniture without damage to any flooring. Being stainless steel, it is rust proof and the wearing surface is not affected by outdoor exposure. The glide itself is large enough to prevent legs from pushing into soft ground.

Part two is a rubber moulded ring which encircles the outer edge of the stainless steel glide. These two parts are held in place in a stamped cup-shaped steel receiver which is arc welded to the furniture legs in the same manner as was the original single disc mentioned previously. In order to hold the small receiving disc in place during the welding, a small tool is used which embodies a rather unique idea worthwhile describing.

The disc is so small that to hold it in place by hand would burn the welder's fingers, even though asbestos, or leather gloves are used. A tool was made from a common pair of automobile kit pliers, (See Fig. 5). One jaw of the pliers was cut away and a copper ring was braised on to the stub of this jaw. The copper ring fits down into the steel receiver which is held in place by the other jaw. This tool has the advantage over a common set of pliers in that the copper ring shields the inside of the steel receiver from all welding splatter, a point most important in fitting the stainless steel and rubber ring into the receiver. With the use of this tool it is possible to hold

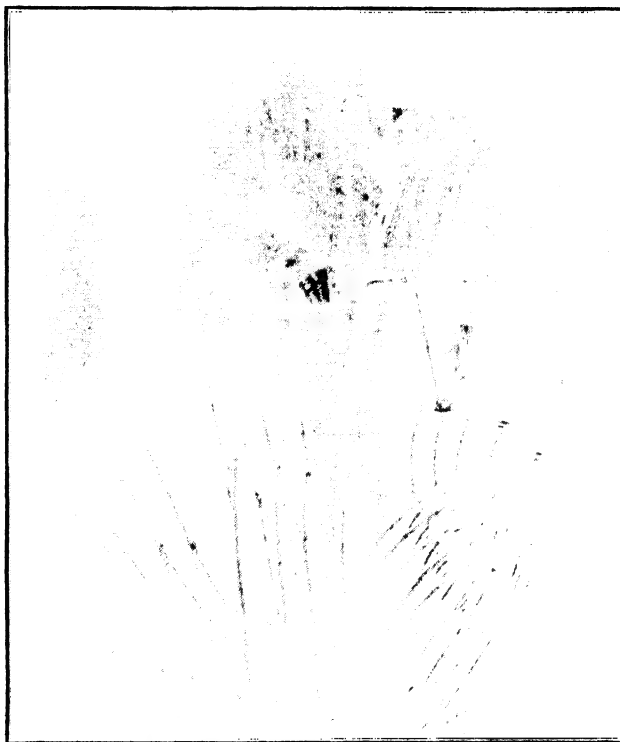



Fig. 6. Welding receiving discs to chair legs.

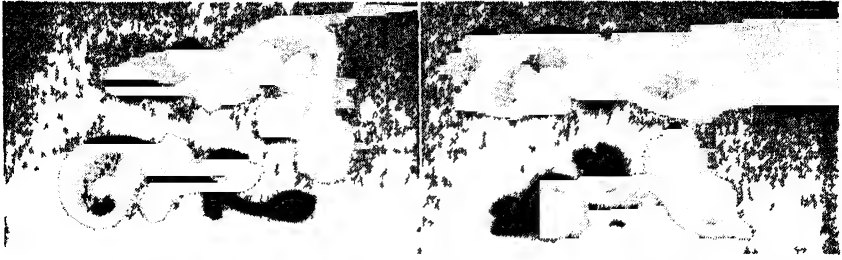



Fig. 7, (left). Typical brass castings for ornamentation. Fig. 8, (right). Ornamental brass castings.

the receiver at proper angle with relation to the leg and floor, even though the welding is done with furniture in upside-down position, (See Fig. 6).

Assembling the three parts of the glide is as follows The first operation is the welding of the cup-shaped receiver to the steel leg The moulded rubber ring is fitted around the stainless steel glide, and these two units are then snapped into the receiver The dimensions of the parts are held to very close tolerances so that when nested together with the rubber ring between, are held in a snap wedge fit Undoubtedly the attaching of our glides could be accomplished by resistance welding, either spot or butt; but for our needs, this method would be entirely impractical because of its inflexibility We use no less than six different sizes of square or round bar stock for legs and these each may approach the floor at any possible angle. For butt welding this would involve a special electrode clamping device for not only each size of bar, but for each angle used for each size. It would also necessitate the machining of each leg and at the proper angle There would even be a question as to whether or not this type of weld would withstand the strain to which it is subjected

While the necessity for developing this glide was not motivated because of our desire to economize, we were pleasantly surprised to find that our cost in making these parts is less than that of standard glides on the market. Even after charging the total expense of dies and rubber mould to an annual production run of 75,000 units, the manufacturing cost of our own glide is $4\frac{1}{2}$ cents each Similar standard glides wholesale for $6\frac{1}{4}$ cents each A savings of 23 per cent or $1\frac{1}{2}$ cents per unit was effected, and on an annual usage basis amounts to $1\frac{1}{2}$ cents x 75,000, or $1,125

A cost comparison of the glides alone does not reveal a true comparison because of intangible elements involved For example, in making a comparison the time involved in attaching the glides should be considered. We have nothing to compare on this basis because none of the standard glides could be practically attached to our steel bar legs It should be sufficient to state that primarily because of the facilities offered by arc welding, we were able to develop a glide meeting our particular requirements and enabling us to offer an exclusive feature not available on other lines of wrought iron furniture

III

Brass Castings—During the latter part of 1940 while we were working on designs for the coming year, it occurred to us that a new field of ornamentation would be opened to us if we could attach decorative metal castings to our steel frames Previously all decorative features, such as forged leaves,

scrolls, etc., had been individually forged or stamped and separately welded to the frames. Our idea was to cast units of various design motifs, such as a running vine of leaves, berries, buds, etc., and to attach this casting to the steel frame. The cost of a cast unit should be much less than to form and weld the individual leaves, etc., into a complete unit. The cast units, although identical, would be so located and arranged with respect to each other as to avoid the undesirable effect of repetition.

In order to have a fine, tracery-like appearance, the castings would be very lightweight and would add little to the structural rigidity of the completed article. Experiments with cast iron proved this material to be unsatisfactory. The welding could be performed, but the castings themselves were too brittle to withstand the flexibility of the frames. Malleable iron castings were then tried; and while they were strong and flexible before welding, the heat applied during this operation reverted the malleable iron to a brittle condition at points adjacent to welds. Breakage still occurred.

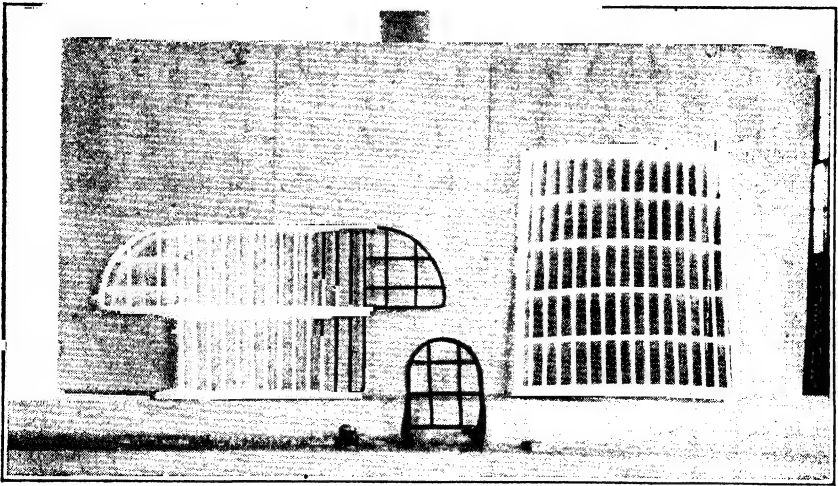



Fig. 9. Brush guard grilles for army trucks.

We had not tried brass because of the higher material cost and because we anticipated difficulty in arc welding the brass to steel. After working with various foundries, however, we found that castings in brass would cost only 50 per cent more than in iron, and even less than malleable iron. In addition, the brass would be sufficiently pliable to withstand the flexibility of the steel frames. The cost would not be prohibitive if a satisfactory weld could be performed. Brass castings, (See Figs. 7 and 8), were obtained and experiments were made in welding with various electrodes. A phosphor-bronze coated electrode proved highly satisfactory. No breakage occurred. During our experiments we found that an 18-8 stainless steel electrode would also give satisfactory results, but was slightly higher in cost. Stainless steel electrodes are often overlooked by welders in attempting difficult jobs, particularly as outlined above for the welding of dissimilar metals.

While we never made an actual cost comparison of the cast unit to that of an individually stamped, formed, and welded unit, our past experience with this method prompted the change. Definite savings, however, are

positively effected. A typical cast unit, (See Figs. 7 and 8), costs 9½ cents each; while a similar unit assembled from pieces could not be duplicated for less than 15 cents. A savings of 43 per cent per unit is a conservative estimate. On the basis of usage during 1941, 20,000 units would result in an annual savings of $1,300.

During the year 1941 and 1942, our findings were successfully put into practice and a large percentage of our production was devoted to items involving the use of brass ornamentation arc welded to steel frames. We were able to offer designs more ornate in detail, yet competitive in price with less attractive articles. To our knowledge this method of design application had not been used by others in our type of work. The enthusiastic acceptance of designs so constructed is the primary attest to the value of this arc welding development to our company.

Conclusion—In addition to the value to our business of the three mentioned developments, our knowledge of arc welding has been one of our greatest single assets in contributing to the war effort. War production has greatly increased the demand for arc welding equipment and operators.

Since August, 1941, when three of our operators, including the writer, were approved as instructors in arc welding, we have been offering Government sponsored vocational arc welding instruction. Some fifty odd men have been trained during night courses. As fast as these men are acceptable, they are referred to the Flint, Lansing, and Bay City plants producing tanks, armored cars, trucks, and submarine chasers.

While our civilian furniture production has been gradually curtailed, and finally stopped entirely effective June 30, 1942, we have readily converted to production of war items, (See Fig. 9). At present writing, 75 per cent of plant capacity is devoted to this type of work.

Chapter III—Bed Rails and Bed Springs

By E. H. Atkinson,

Mechanical Engineer, Fulton Metal Bed Manufacturing Co., Atlanta, Ga.

E. H. Atkinson

Subject Matter: Bed rails and frames for bed springs are usually made of angle iron. When the war demand made it impossible to obtain angles from the mills for this purpose, this company conceived the idea of using the plate trimmings from the tin plate mill, which the mill was permitted to roll into shapes to suit and sell. These trimmings were too thin to have the required strength when rolled into the standard sized angles for the bed rails, so the shape was changed to a channel.
For the bed springs, the cross slats were usually made of 1-inch x 1/8-inch steel bands. These were changed to 1¼-inch x 1¼-inch angles rolled from trimmings. The connections were all made by welding.

The object of this paper is to show how a manufacturer of metal beds and bed springs when deprived by war demands of his conventional hot-rolled-steel shapes turned to an arc welded design using shapes that he could obtain and thereby continued operation of his plant.

To appreciate the necessity of change, let us look back to early 1941. Most of the world was at war or was preparing for war. With the lend lease program in full swing, and with the National Defense program building army camps, warehouses, and numerous defense industries, manufacturers of civilian goods made of steel began to feel the pinch of steel shortages during the middle of the first quarter of 1941. Before the end of the first quarter the steel mills were refusing orders for material not going into defense work. The last hot-rolled shapes this manufacturer received were ordered in February, 1941, and were delivered in November, 1941. So, to continue the making of metal beds and springs it was necessary to change to some material that was obtainable.

The large steel mill which had been the sole source of supply for several years was by then engaged in rolling tin plate stock and shell stock. At the end of the hot rolling of this stock, and before the cold rolling, the edges of the sheets had to be trimmed to cut away the edges which were laminated and checked, that is, the sheet had to be squared back to good solid stock perfect in structure. These trimmings were waste and had no value other than scrap to be re-melted. The government was, and still is (May, 1942) permitting the sale of this material for non-war work.

But to work this material into metal beds and springs, the customary method of manufacture had to be abandoned and a welded design was the answer to the problem.

In the summer of 1941 we began to run out of the regular angle iron side rails for metal beds, and also the slatted steel bases for bed springs. So, we set out to make bed side rails and spring bases from the steel mill scrap.

First let us consider the bed side rails. The bed side rail is that part of the bed which extends from the lock on the head of the bed to the lock on

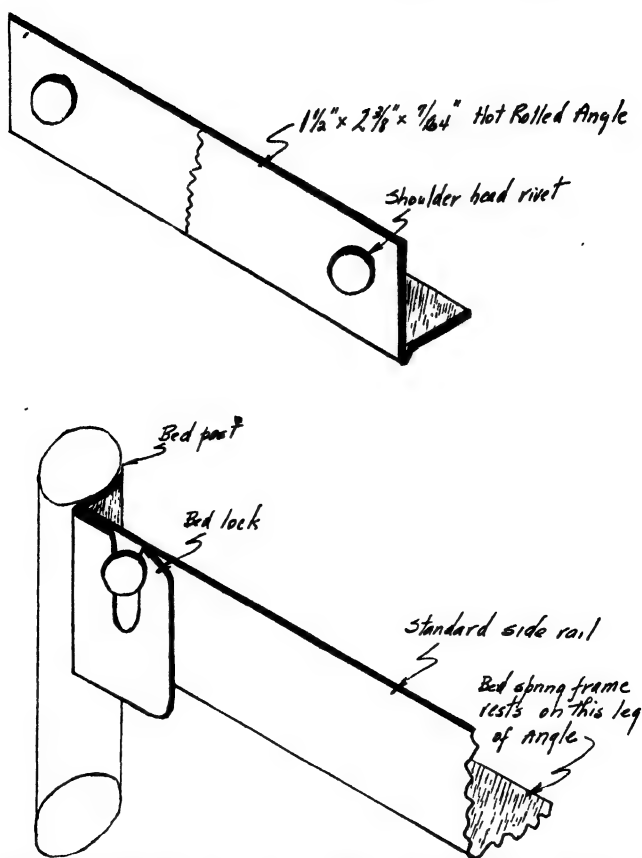



Fig. 1. (above). Standard bed rail. Fig. 2. (below). Attachment of standard side rail to bed lock.

the foot of the bed. The two rails hold the head and foot of the bed in firm upright positions and also provide a support for the bed springs. The standard metal bed side rails are made of 1½-inch by 2⅜-inch by 7/64-inch hot-rolled rail-grade steel angles. The short leg of the angle is notched on each end (to clear the rivets that hold the locks to the bed posts) and shoulder head rivets are riveted in the long leg of the angle near each end of the rail, (See Fig. 1). These rivets fit into the bed locks on the head and foot posts as shown in Fig. 2.

The steel mills had the necessary equipment for cutting the trimmings to size and could then cold-form them into various shapes. These shapes were, of course, limited to what equipment and rolls on hand as the mills could not increase their facilities for non-war work. Had the trimmings been of sufficient thickness, a 1½-inch by 2⅜-inch angle, the same leg dimensions as the standard bed rail, could have been formed and this substituted for the standard hot-rolled angle, but the available stock was so thin, an angle made of it did not have sufficient strength and would bend to the floor when used as a bed side rail. However, the steel mill did have rolls for shaping the metal in the shape shown in Fig. 3. Being a box section, this section had plenty of strength, but no place to fasten the necessary shoulder head rivet. To over-

Fig. 3. Shape of available section.

come this, the rivet was riveted into a flat plate of the same scrap steel and electric welded to the box shape. To allow clearance for the rivets holding the lock to the post, the welded on plate was allowed to project past the ends of the box section. One end of the completed rail is shown in Fig. 4.

This new bed rail was approximately the same weight as the standard rail. It was nice looking, satisfying to the trade, and was stronger than the standard hot-rolled angle.

Before going into the cost, let us consider the changes in the spring bases and carry the two costs along together.

The standard spring base for steel-base coil springs (the same base is used throughout the entire country with only very minor changes) consists of a 1¼-inch by 1¼-inch by 7⁄64-inch angle bent to form a continuous frame and usually resistance welded. For a standard double bed this frame is approximately 52-inches wide and 6 feet long. Eight or nine 52-inch cross slats

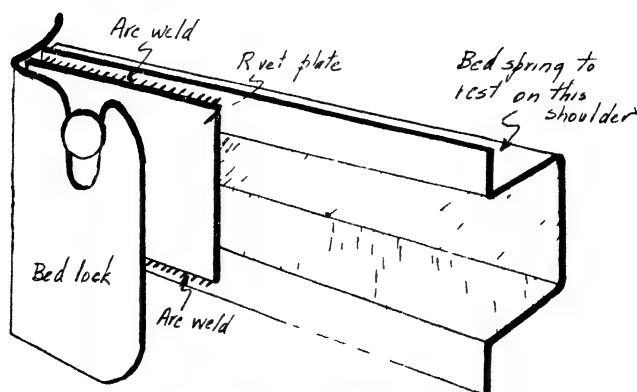



Fig. 4. One end of completed side rail.

are riveted in forming a slatted steel base upon which to fasten the coils. The cross slats are usually ⅛-inch by 1-inch hot-rolled rail grade steel bands, twisted at each end so that the one-inch side of the band is vertical. Fig. 5 is a sketch of the standard frame.

When the hot-rolled shapes were no longer available, and we started to design to use the trimmings, we found that the trimmings shaped into a 1¼-inch by 1¼-inch angle was sufficiently strong for the one piece continuous frame, but that the same trimmings cut into strips 1-inch wide and used for cross slats like the standard ⅛-inch by 1-inch hot-rolled bands did not have the necessary strength to resist bending. We had the trimmings shaped into 1¼-inch by 1¼-inch angles which, of course, would resist a large bending moment. These angles were then placed in crossways of the continuous frame and welded in place, (See Fig. 6). (Note: A cross angle made of the trimmings 1-inch by ½-inch would have had sufficient strength, but the steel mill only had rolls available for rolling angles 1¼-inch by 1¼-inch or larger. Conditions were such that you had to take what you could get and not what you wanted, or do without.)

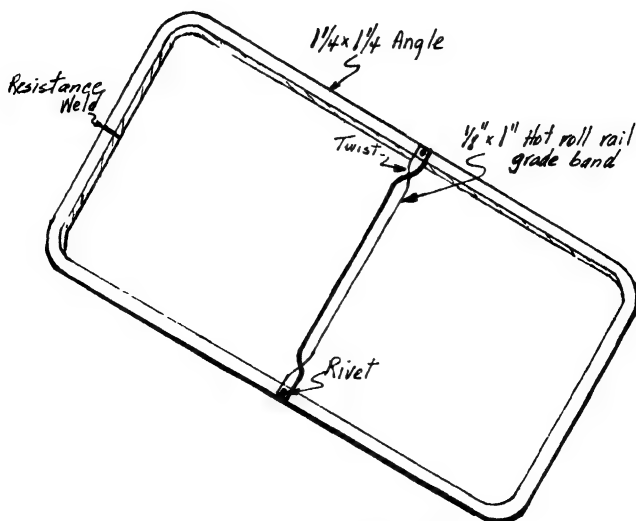



Fig. 5. Standard spring base.

The welded side rails and the welded spring bases were both stronger than the standard design which they replaced. However, this extra strength did not have any particular value to the manufacturer in that the standard design was strong enough for the purpose. In using angles of the trimmings in place of the regular flats in the spring bottoms, and in using the box-section side rail in place of the regular angle, many more square inches of material was used in the welded design, but with this material only one-half as thick as the regular shapes, the total weight for the side rails was the same for both designs, while the spring base was slightly heavier than the standard. The scrap steel was a mild steel having a higher base price than rail-grade steel and by the time the cost for cold-forming these trimmings into the shapes necessary to get the required strength, the material costs for both items were higher than the standard.

To cover the cost increases the manufacturer had to add 25 cents to the selling prices of the beds (20 cents additional material cost, 5 cents additional labor) and to the selling prices of springs 50 cents was added (40 cents additional material, 10 cents additional labor). Even with these increased prices, the manufacturer could not supply the demand since competitive manufacturers were ceasing production for lack of their standard shapes. Of course these welded designs will be abandoned when the steel mills resume normal production, but for the present it is letting this manufacturer continue production of a vitally necessary commodity that is going largely into defense

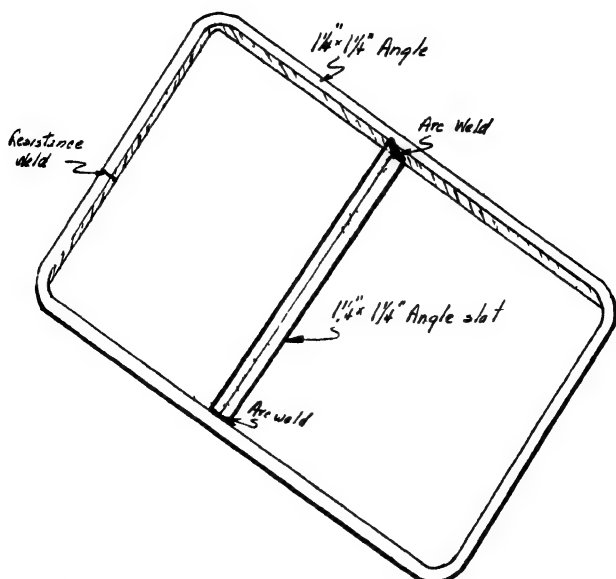



Fig. 6. Spring base of trimmings shaped as angles.

centers for civilian workers. At the same time, the manufacturer is keeping his plant in operation, keeping his old customers supplied with merchandise, and keeping his employees at work. There is no economy at 25 cents and 50 cents per item higher prices, but when the demand cannot be met even at the higher prices would there be economy in letting the plant and the employees stand idle for lack of standard steel shapes?

The changes to the two welded designs were carried on in the plant with the employees and equipment already on hand. Of course jigs were made for both the side rails and the spring bases so that the individual pieces could quickly be placed in the proper positions and held there positioned for the easiest welding. Two jigs for each item were made so that one man could load and unload for the welder.

After getting our jigs made we were able to maintain normal production of 375 beds per week and 475 bed springs per week, and the steel mill accumulated much more trimmings than we could use.

Chapter IV—Welded Housings for Telegraphic Printers

By PAUL J. BIRKMEYER,
Engineer, Western Union Telegraph Co., New York, N. Y.

Paul J. Birkmeyer

Subject Matter: Designs of arc welded table and printer cover as separate units. These were replaced by an integral arc welded unit called "Printer Console" combining the services of a table and machine cover and adding certain other features of which the maintenance shelf is important. Consoles are built for multiple copy printers. Statistics on costs show table and cover combination at $50 and arc welded printer console at $40. Number of printers in service is approximately 50,000. The value of the console should be considered in the light of many indeterminable factors such as appearance and space requirements, as well as noise reduction, utility, and pride and satisfaction of the user.

"By Teletype" is a popular expression referring to the modern person to person, direct wire, printed communication, just as "by phone" has meant, for many years, the communication of the spoken word. However, while teletype is, to the printed word, just what the telephone is to the spoken, it is by no means so familiar as the ubiquitous telephone, and thus a brief description of the modern telegraph printer may be warranted.

The printer is a machine similar to a typewriter, with a keyboard and printing mechanism including a typewheel or typebars. While the keyboard of a typewriter actuates its own typing or printing mechanism, the keyboard of a printer actuates the printing mechanism of a distant printer, by electric impulses sent over the line. As a convenience and means of ready reference to the typist or operator, the circuit is generally arranged to produce a copy of the message being sent, on the home printing mechanism.

Printer Console—This paper refers in general to the design and construction of enclosures or housings for telegraph printers, and in particular to recent improvements in their appearance and utility by the introduction of the "Printer Console". The present printer console is a complete unit housing, arc welded and constructed in accordance with modern design practices.

Printers are used in business organizations, police and Federal Intelligence systems, military communications networks, news services and all other activities which may require rapid and efficient communication service in record form. In the past, these printers, of varying design, have generally been installed on tables, also of varying size and construction, as shown in Figs. 1, 2 and 3. The printer is supported on a base with rubber mountings and enclosed inside a cover to protect the mechanism from dust particles. The inside of the cover is lined with acoustic padding to reduce to a minimum the transmitted noise of the printer.

Referring to Fig. 1, the table is of arc welded construction throughout, as is the printer cover. A plate for a signal light, power plug, line plug and

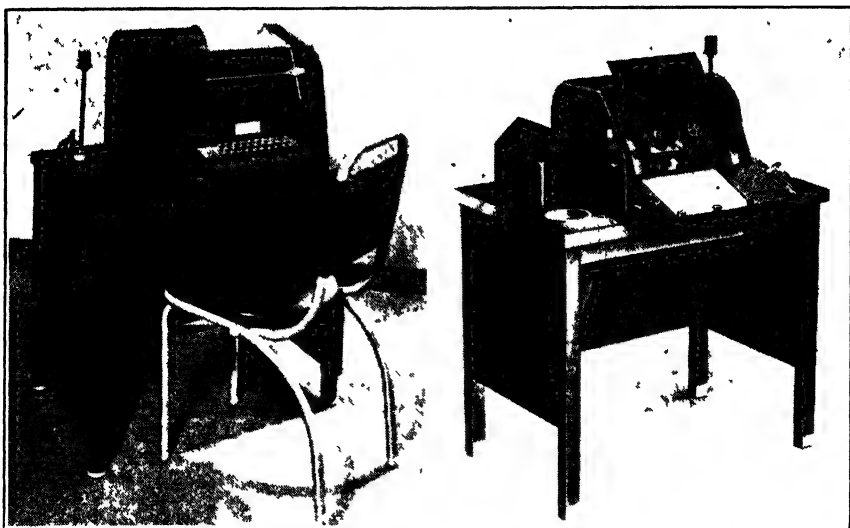



Fig. 1. (left). Arc welded table and cover for printer. Fig. 2. (right). Another printer with arc welded table and cover.

switch is shown to the left of the cover. A metal wiring cabinet for electrical equipment is attached to the under side of the table and protrudes through it, under the plate. For servicing the printer, it is necessary to remove the cover which, in crowded offices especially, proves somewhat of a nuisance unless a special table is provided for the cover.

Fig. 2 shows a printer which prints on a narrow strip of paper tape. The table in this instance is of steel arc welded construction, finished to reproduce popular wood graining. The printer shown in Fig. 3 is installed on a small wood table of the usual walnut or mahogany finish. In this case the wiring cabinet with a control switch is mounted under the table, while the signal light, power plug and line plug are mounted on the table top within the confines of the cover.

Many thousands of printers have been installed and are in use today on tables of the three types shown. The tables were furnished as standard until early in 1940, and in some cases are still being furnished, due to shortages of materials required for the manufacture of printer consoles. It will be noted that modern arc welding practices were followed, especially in the construction of the table and cover shown in Fig. 1.

In appearance, the tables and covers do not form a harmonious whole, as a combination of separate parts, each part for its own specific purpose, invariably produces a stilted or "built-up" impression. It was to overcome this stilted appearance, as well as to conform with modern design of furniture and fixtures, that the printer console was introduced early in 1940. It is shown in Fig. 4 in normal operating position, and in Fig. 5 with doors opened and the printer placed on a maintenance shelf to facilitate servicing. All auxiliary parts required for operation, including wiring cabinet with signal light and switch, printer base and paper roll, are enclosed within the console.

The console is constructed primarily of 14-gauge cold rolled steel, stretcher leveled. It may be noted in the pictorial view that arc welded construction is employed throughout. Welds along surface joints or seams are continuous. On flat surfaces, they are ground smooth. Along contour edges or corners,

all welds are carefully ground to a uniform radius to match adjacent bent steel sections. Inside joints are secured by tack welding or short arc welds at spaced intervals. Auxiliary steel parts such as hinges, channels, angles, straps, tubes, etc., are attached in like manner.

The maintenance shelf shown in the sectional plan view of the drawing consists of a rectangular pan with sides and bottom flange welded at the four corners for rigidity. The pan is fastened to the under side of the front apron by a continuous hinge. It is supported in open position by telescopic square tubes angularly spaced, with the outside tubes welded to the pan and the inner tubes extended and braced against the side walls of the console. To close the shelf, the inner tubes are released from the side wall pin catches and telescoped within the confines of the shelf, which is swung into position under the deck of the console and held by a catch.

A wiring cabinet of arc welded construction is mounted on the thick wood deck as shown in the partial view. It is mounted to the wood deck in order that it may be readily removed to allow for variations in the auxiliary wiring material depending on the electrical requirements of the circuit. The thick wood deck provides an effective barrier to the transmission of noise.

The construction methods indicated on the drawing are those preferred in several well equipped sheet metal factories. Alternate methods of construction and attachment, especially with reference to parts inside the consoles, may readily be employed as dictated by the machinery at hand and the number of consoles involved in specific orders or contracts. Consoles are subject to minor variations to meet the different printer and operational requirements. Orders for consoles have accordingly been limited to quantities of 300 to 500.

Console for Multiple Copy Printers—The console and tables described in the preceding paragraphs are used with printers producing single copies,

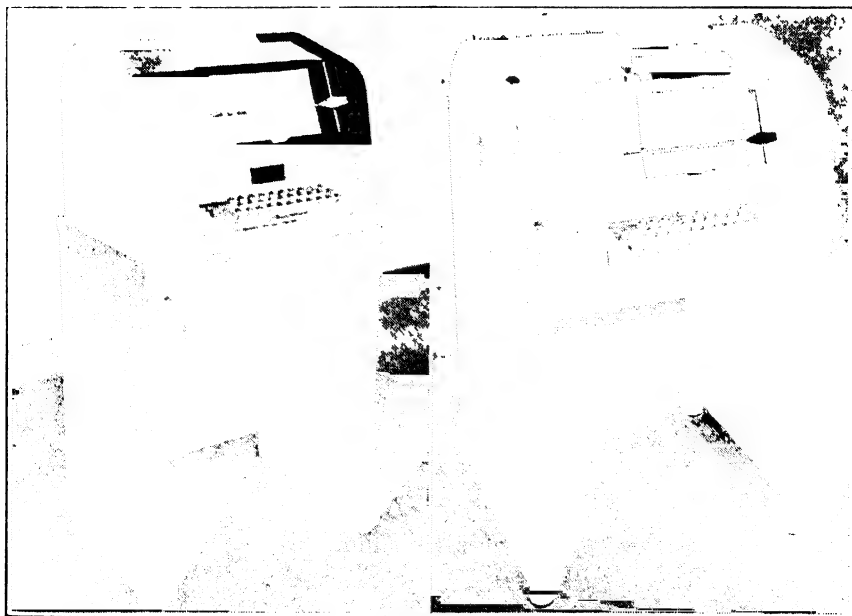



Fig. 3. (left). Table and cover for installation in limited space. Fig. 4. (right). Modern printer console arc welded throughout.

Fig. 5, (left). Arc welded printer console in open position. Fig. 6, (right). Table and cover for multiple copy printer.

the paper being fed from a roll. By the addition of an attachment known as a sprocket feed, multiple copies on carbon are produced. In this instance, the paper is stacked in fanfold as shown in Fig. 6. The table is identical with that shown in Fig. 1. The use of another addition to the table and cover combination, amplifies the "built-up" impression produced as of a home made or temporary expedient.

A console for multiple copy printers is shown in Figs. 7 and 8, front and rear views, respectively. It is similar to that shown in Fig. 4, with the exception that a compartment for fanfold paper has been built into the body. This compartment has a door in front as well as in the rear to facilitate loading, especially in cases where the console is placed against a wall. This console, compared with the single copy printer console previously described, demonstrates the flexibility in shape and dimensions attainable in arc welded construction. No expensive dies are required to provide such variations as the characteristics of the machine or the requirements of the user may suggest.

A Product of Industrial Design—Industrial design, an activity utilizing modern design and construction practices (in many cases arc welded construction), has produced effects popularly (but in many cases improperly) described as "streamlined". The value of such designs in the construction of many articles, used in business and in the home, has been clearly demonstrated in sales appeal.

While the limits of industrial design are indefinite and subject to personal interpretation, the printer console could readily be considered within the limits of such design. It is constructed as a unit to dimensions and contours to meet the physical and mechanical requirements of the machine it serves. Of utmost importance, however, have been the requirements and desires of the user.

The importance of arc welding procedure, in providing finished unit steel

products such as consoles which must be flexible in matters of size and contour, cannot be overemphasized. In fact, it would be impractical to consider construction in any other manner. In consideration of the clean, effective lines and finish, it may not be amiss to call attention to the absence of any unsightly screw heads or rivets, which may be verified by a glance at the photographs. As a matter of information, console installations may be seen in practically any city of importance in the country.

Statistics

A. Record of Comparative Costs*

Table and Cover Combination

Item	Cost
Table Framework	$10.00
Table Top-Plywood with Phenolic Fiber Surface	5.00
Printer Cover	12.00
Printer Base with Rubber Mountings and Cover Support Plate	7.00
Wiring Cabinet with Hinged Access Door	4.00
Top Plate for Wiring Cabinet (Special Bakelite)	2.00
Bracket for Paper Roll	1.00
Total Cost of Parts	41.00*
Assembly Cost (not req'd with console)	6.00
Additional Shipping and Handling Costs (estimated)	3.00
Total Assembled Cost (not including printer and associated electrical equipment)	$50.00

This figure ($50) does not include a maintenance shelf or other means for holding the printer cover during periods of maintenance.

Printer Console

Item	Cost
Console, complete with maintenance shelf, printer base, wiring cabinet, roll bracket and all items with the exception of the printer and associated electrical equipment and comparable with the assembled cost of table and cover combination	$40.00*

* These costs (cents omitted) are taken from contracts placed for these items in 1940. They represent the delivered price to the buyer.

The delivered cost of the console ($40) includes many items extraneous to arc welding. For purposes of information and to place arc welding costs in proper relation to the total cost of a console, average breakdown costs as prepared by manufacturers have been studied. Based on 20 per cent gross profit but not including factory overhead and incidentals, the cost of manufacturing complete consoles packed for shipment amounts to 80 per cent of $40, or $32 each. Of the $32, the cost assembled in place of parts and material extraneous to arc welding amounts to $17. Such parts and material including labor, include plastic window, maintenance shelf, wiring cabinet and plate, printer base and rubber mountings, wood deck, acoustic padding, rubber and felt parts, hardware, baked crinkled finish, name plates, packing for shipment and minor incidental parts and material.

It is interesting to note that the cost of manufacturing the bare steel console proper, as shown in the pictorial view of the drawing, amounts to less than half of the total cost, or $15. Of the $15, the cost of the steel, including

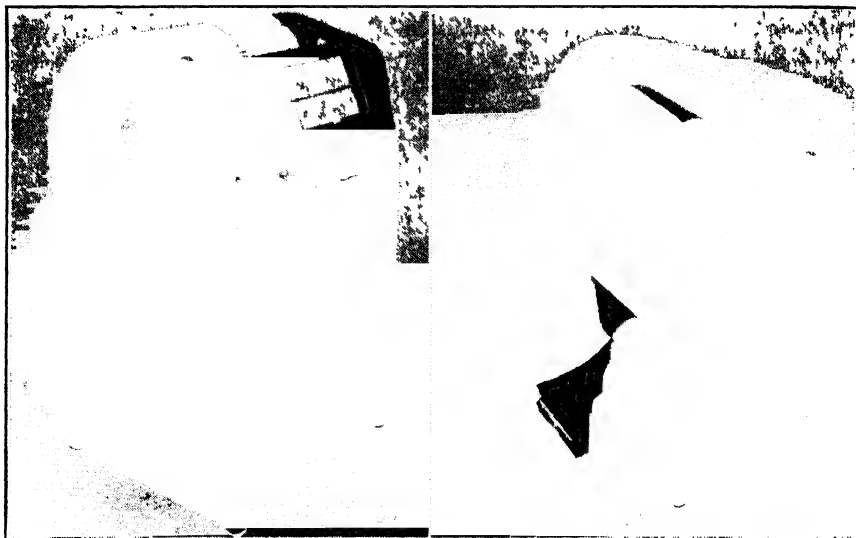



Fig. 7. (left). Console for multiple copy printer. Fig. 8 (right). Rear view of console for multiple copy printer.

wastage, amounts to approximately $6, allowing approximately $9 for blanking and forming the parts and assembly by arc welding and grinding of all exposed welds.

B. Printer Installations

Installations in customers' quarters by various companies may be tabulated as follows:

American Telephone & Telegraph Co. (TWX Service)	14,863*
American Telephone & Telegraph Co. (Private Lines)	7,281*
Western Union Telegraph Co. (Tie Lines)	13,600**
Western Union Telegraph Co. (Telemeter Service)	1,200**
Postal Telegraph Co. (Tie Lines)	6,983**
Associated Press, estimated	1,500
Other Privately owned systems, estimated	1,000
Estimated Growth for 3 companies since Reports to F.C.C.	3,500
Total Printers in Service (partly estimated)	49,927

*From Report to Federal Communications Commission, December 31, 1940.
**From Report to Federal Communications Commission, December 31, 1941.

Conclusion—Improvements in arc welding procedure or in the art of arc welding are of tremendous value economically and socially in normal times. In these war times, improvements are of incalculable value from a military standpoint. Of equal or of even greater value are improvements in design for arc welding. The printer console as described in this paper is respectfully submitted for consideration in the category of improvements in design.

Referring to the Record of Comparative Costs, we note that a console, which is the modern improved design for a printer housing, actually costs $10 less than a combination of table, cover and other associated parts to serve

the same purpose. This simple comparison of costs, however, does not portray a true value of the design in its broader aspect. A printer represents an investment of hundreds of dollars and considering its wide usage in well furnished offices, it should merit an attractive housing in keeping with its surroundings. It is always difficult to place a monetary value on improvements in appearance of equipment, especially the equipment of service companies, which is normally not for sale. If, however, the printer in console may be considered a DeLuxe model of a separate table and cover combination, the improvement in design should reasonably be valued in multiples of the actual $10 saving in cost.

From the record of installations, we note that approximately 50,000 printers are in use in customers' offices. Of these installations, approximately 1,500 are enclosed in consoles. Additional installations are being made regularly dependent on the availability of steel.

As previously discussed the actual monetary saving on each console is $10, the reduction below the cost of its predecessor, the table and cover combination. The use of the console for each of the 50,000 printer installations would result in a cash saving of half a million dollars. The value of the console as an improvement in printer housings should, however, be considered in the light of many indeterminable factors such as appearance and space requirements, as well as noise reduction, utility, and pride and satisfaction of the user. All of these factors have a direct bearing on the accuracy and efficiency of the operator, and far overshadow the half million dollars in cash saving. The value of the console may therefore be considered in terms of millions of dollars.

Chapter V—Pipe-Frame Office Chair

By Eldridge T. Spencer,
Architect, San Francisco, California.

Eldridge T. Spencer

Subject Matter: An office chair which was functional and modern in appearance, adjustable in height and back support, movable, compact and economical in maintenance was desired. Designed by the author, the framework was made of arc welded steel pipe. The back is on swivel joints so that it follows the body in leaning or straight position. The seat height is adjustable by moving it back and forth as is done on automobile seats. The frame is mounted on rubber casters. Appearance is definitely functional. Seat and back are upholstered over foam rubber and, hence, can be re-upholstered when nceessary. The back is mounted off center so that adjustment is made by merely rotating it through 180 degrees.
Since the chair is not to be carried, the weight of the steel over lighter metal added stability. In the 1941 chair of similar design, the rear leg, arm and back support was one piece of bent pipe. Bending cost $2.00 per leg. In new design by using straight sections and adding two welds, the cost of welding was 50c per leg. An estimate of 15 per cent saving by using arc welding is made. The chair meets all the original requirements.

Design—When a certain corporation finished its chemical industrial plant in California in 1941, the owners began looking for a chair that they could use in their administrative offices. These were housed in a completely functional, modern streamlined building. The chair was to be used at long stationary desks fitted with demountable extension wings. It was to be adjustable in order to accommodate slim girls as well as two hundred pound men. Since men and girls often changed places all adjustment was to be quickly made. In addition the chair was to be easily movable from side to side and back and forth to allow for work at the desks when the extension wings were in place. For economy of space the chair was to be compact. For economy in cost it was to have no extraneous detail or ornament. For economy in maintenance it was to be durable and the parts easily replacable.

When the corporation failed to find a chair that fulfilled these requirements they asked the architect of their plant to design one for them. The architect, the writer of this paper, designed not one but two. It is the second of these, or more accurately speaking, the pipe frame of the second which is entered in competition. After experimentation it was decided that the easiest adjustment to make for height of occupant was the backward and forward sliding adjustment of seat that is used in the driver's seat of an automobile. Therefore the seat was made to slide on the two side pipes of the supporting frame and held in place by means of a butterfly nut. As in an automobile this adjustment could be made while sitting in the chair.

An adjustment of the back was made also, both for height of occupant and for posture. In recent years employers have become aware of the importance of posture particularly in the case of sedentary workers whose posture depends largely on the chair provided by the employer. For good posture the back of the occupant must be constantly supported in an upright

position. This means that the angle of the chair back should change as the occupant leans forward or back. In the chair under discussion a straight back revolves on a swivel joint nine inches above the seat of the chair. As the occupant leans forward the back follows and vice versa. Furthermore, though the back is symmetrical top and bottom, the point at which it swivels is offset one inch from the horizontal center. This makes it possible to raise or lower the top of the back two inches simply by revolving it one hundred and eighty degrees. To add comfort to good posture seat and back are cushioned with two inches of foam rubber.

The chair is compact. The arms extend only ten and one half inches from the line of the back, far enough to give support and not far enough to interfere with easy access to the lower compartments of the desk. In fact all parts of the chair are made as small as their proper functioning permits. Front legs are perpendicular and set just back of the front line of the seat. Rear legs which extend upward to support the arms are snubbed in at the base so as not to occupy too much space. So that the chair may move easily as the occupant turns from side to side or pushes back, it is fitted with two

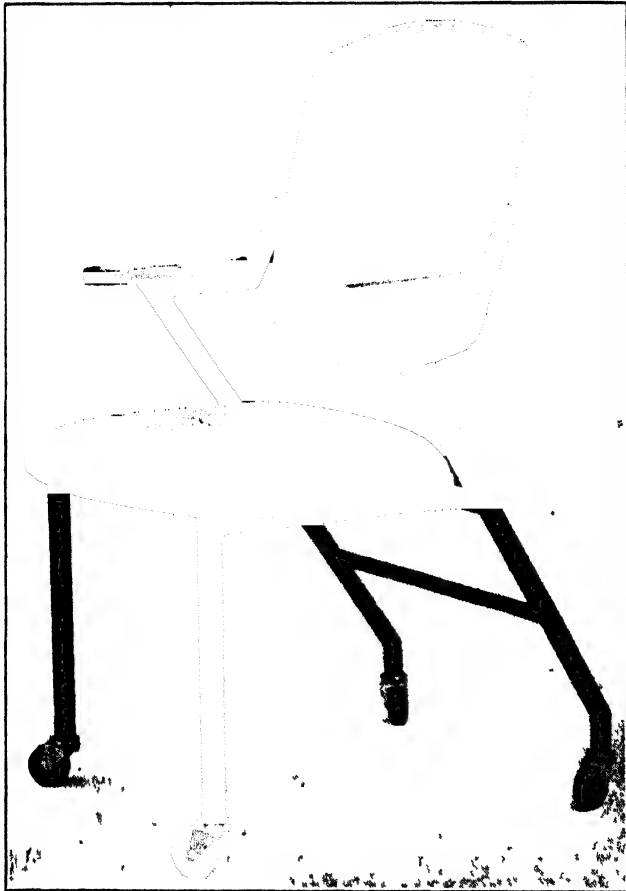



Fig. 1. The subject of study.

inch commercial rubber casters which roll noiselessly over a smooth concrete floor kept at a comfortable temperature by radiant heat.

In addition to being easily movable, compact, comfortable and easily adjustable thus fulfilling the requirements of function, the chair, (See Fig. 1), fulfills other requirements of good industrial design, namely that materials be used efficiently and frankly and that good engineering be synonymous with good esthetics.

Considering first the use of materials, the frame only is of pipe chosen for strength and availability. The frame has no moving parts. The frame is a good example of precision design made practicable by arc welding assemblage. It is the frame that is the subject of this paper. The seat and back are of plywood chosen for relationship of strength to weight and size and for ease in cutting. Seat and back are cushioned in foam rubber chosen for comfort and simplicity of assemblage and upholstered in mohair frise chosen for durability and considered preferable to leather or fabricoid since mohair decreases wear on clothes and does not tend to stick in hot weather. Arm rests are of wood used because wood is warmer to the touch than is metal. The chair could be complete without casters.

Considering the requirement that good engineering be synonymous with good esthetics, the chair has style. That which has given it style more than anything else is the solution of the problems of manufacture and the use of arc welding. Indeed, without welding, it would be impossible to realize the full engineering and style possibilities of the pipe. For comfort, the arms, at the point where they are supported by the rear legs, are three inches further apart than are the legs where they meet the floor. For facility of manufacture, rear leg, arm support and back support are on one plane so that the pipe can be placed in a jig and quickly tacked by arc welding. This being the case, as legs are brought together at the floor arms slant outwards giving the chair an inviting air.

The definition of planes is made as precise as possible and the number of planes reduced in the interest of fabrication first and of style its inevitable counterpart second. The planes are six: those of the rear legs, arms and back support, that of the rear legs and stretcher, introduced for strength but contributing to style, the plane of the back, the plane of the seat and the plane of the front legs.

The pipe frame has a baked enamel finish. The walnut arm rests a varnish finish over bleach to harmonize with the wood of the desk tops. These high polish finishes are durable, easy to maintain and contrast pleasantly with the texture of the mohair back and seat. The pattern of the upholstery is geometrical and appropriate for a chair whose style depends on precision engineering. It is based on diagonals and realized in texture rather than in color. Color, both of mohair and of pipe is a slightly grey Copenhagen blue, the same color that is used on the steel sash of the windows of the offices where the chair is installed.

Fabrication—The frame of the chair is constructed of three quarter inch commercial steel pipe chosen for its strength and availability. At the time of fabrication there was thought of using tubing. However this was not obtainable. To the delight of the designer, the weight of the chair, thirty pounds, has given it stability and reduced the hazard had a lighter tubing been used of the chair skidding out from under its occupant. Furthermore, since the chair never has to be lifted, the weight is in no way a detriment.

The chair has eighteen welded joints, all of which join only two pieces of pipe, never more, to simplify fabrication. For example front support of

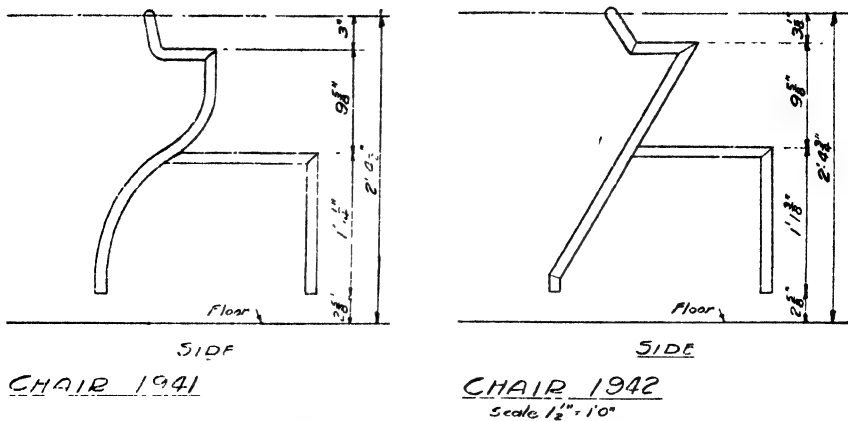



Fig. 2. Details of chair frame, 1941 and 1942.

chair seat joins with side supports just back of joint of front leg with side support. From the point of view of fabrication, design and style the most interesting part of the chair and of the chair frame is the rear leg, arm and back support. The four pieces of pipe forming this member were placed in a right hand jig, tacked with an arc weld, then placed in a left hand jig and tacked again. Once these members were assembled they were held in place with spacers and the back support of seat and the stretcher welded in place. The whole design of the chair depends on the accurate alignment and rigidity of this portion of the frame, for the frame, at the points of support of the revolving back, must not only be strong but must never vary in width. To prevent any tendency of these points to spring apart the back stretcher was introduced. To secure speedy and perfect alignment arc welding was necessary.

As was stated earlier, two chairs having the same functional requirements were designed for the Corporation, the first in 1941 and the second in 1942, (See Fig. 2). The chairs were identical except for the form and construction of the rear leg, arm and back support, which in the 1941 chair consisted of a curved pipe as shown in the drawings. In the 1942 chair, costs were cut and time of fabrication reduced when the curved pipe was replaced by straight pipe and two additional welds.

Bending pipe in the 1941 chair cost $2.00 per rear leg, arm and back support. The additional two welds in the 1942 chair cost $.50. The difference, $1.50 per rear leg, arm and back support or $3.00 per chair is the savings made by the change in design and fabrication. As the pipe frame of the 1942 chair cost $15.00, this savings amounts to 20 per cent. An additional savings of 28 per cent was made in the time of fabrication as the 1941 chair frame having curved pipe was more difficult to assemble. It is interesting to note that the improvement in the 1942 chair was due to lack of equipment to build the first chair as the pipe bending machine used in the fabrication of the 1941 chair, in 1942 was in use in the airplane industry. The result was a better, cheaper chair that could be fabricated in any shop equipped with a pipe cutting saw and an arc welding outfit.

It is difficult to estimate the total annual gross savings accruing from the use of arc welding by the company which produced the chairs or the total annual gross savings accruing from arc welding in industry in producing

chairs of this type. The company, the manufacturing company, cannot now, on account of priorities and restricted use of critical materials, continue production. Furthermore this chair could not have been produced at all had it not been ordered by a firm engaged in war industry which had a high priority rating applicable to the purchase of equipment at the time the materials used in the chair were purchased.

It is possible to estimate in percentage the savings made in the manufacture of this chair by means of arc welding over its possible manufacture by some other reasonable means of manufacture such as acetylene welding. Were the assemblage of the frame by arc welding abandoned for its assemblage by acetylene welding it would be necessary to clamp the pipe into a form before welding. This would be a more time consuming process than that of placing the pipe in a jig and would add approximately 15 per cent to the cost. Or saying it the other way around, the savings accruing from the use of arc welding in the production of the chair can be estimated at 15 per cent.

Advantages—The chair is an exceedingly durable structure. Its pipe frame should last as long as the concrete and steel buildings which comprise the plant where it is installed. Strength of the pipe makes elimination of stretchers possible, which in turn makes movement of occupant easy, facilitates janitor service and dusting, and decreases destruction of silk stockings.

The chair is easy to maintain. Parts most subject to wear are simple to remove and replace; for example, casters, arm rests, seat and back. They are also easy to reproduce or to reupholster. Actually the mohair on the seat and back is an exceedingly durable fabric so that reupholstering should not be necessary for many years.

The chair is very simple to produce. In the normal market all of the materials used are quickly available. Furthermore, as the pipe frame can be assembled without the use of heavy pipe bending machinery, it is a product suitable to produce in small shops. At the same time, its adaptability by means of easy adjustments makes it a product suitable for large scale production.

The chair's adjustability to size of occupant and the good posture it tends to enforce give it great social advantages. Good posture is a necessity of good health and especially in the case of the sedentary worker tends to eliminate fatigue. Elimination of fatigue means greater working efficiency and an enormous saving in man hours. This saving and all the other advantages of the chair may be considered a result of arc welding, the method by which the pipe frame was assembled and the most speedy, economical and practicable method of such assemblage.

General Data—The chair frame which is the subject of this competition is made of commercial steel pipe assembled by arc welding. It weighs sixteen and three-eighths pounds. It cost $15.00. Due to a shortage of material only twenty-four chairs were manufactured. This chair frame was designed by the author for the Turlock, California Plant of the Chemurgic Corporation. It was fabricated following full size drawings supplied by the author.

Chapter VI—Welded Display Holder for Printed Matter

By Victor Paul Weidner
Engineer, Western Union Telegraph Company, New York, N. Y.

Victor Paul Weidner

Subject Matter: Holder so designed that printed matter will not droop quickly. Photographs and prints of a wooden, a plastic and an arc welded unit are included. A comparison chart presents the essential features rather uniquely.

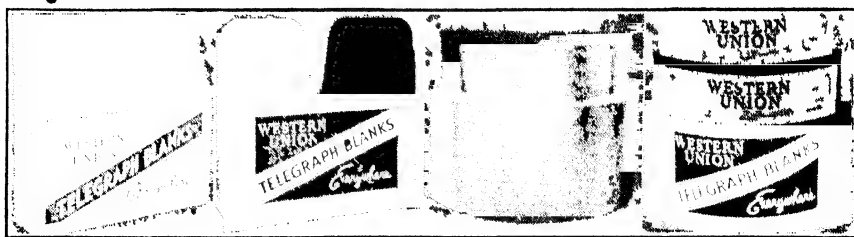
Prior to 1940, holders to display printed matter were made of wood but were considered unsatisfactory because of their high upkeep. To replace these, the author substituted a new design to be molded from plastic, hoping that this type would be a better solution but the experiment was not quite feasible. Further research was carried on which resulted in the design of a metal holder. This last type has been selected as the subject of this paper.

During the period in which the final design was under consideration it was discovered that curving the front faces of the holder helped to stiffen the printed matter which heretofore had had the tendency to droop at the top, thus hiding its caption line or title. This drooping effect had been caused by the action of humid weather on the paper stock or after being displayed for a short period of time.

Ten test models were fabricated for our exhibits at the 1940 New York World's Fair where they were subjected to every kind of hard service. These models were made of sheet brass with brazed joints and were chromium plated for show purposes. This model proved too expensive to make up in large quantities, therefore, it was decided to use sheet steel. As this holder was to be the first metal-type equipment to be installed on the counters in the company's branch offices, its appearance was an important factor. All joints had to be neat and clean-looking and no hazards were to be reckoned with under usage by our customers. Welded seams ground off smooth or to a small radius were then specified on the drawings. The design has been standardized for general use and is stocked at our company warehouses throughout the country.

The Comparison Chart—All information that is necessary for the proper comparison of the three types of holders has been entered on the accompanying "Comparison Chart". It is hoped that this method of illustration will facilitate the analysis of the paper. There have also been included four photographs, Figs. 1, 2, 3 and 4 showing the 3 types.

Factors	Wood Type	Plastic Type	Welded Type
Indestructability	See Drawing – Use of 1/4" wood stock with tongue and groove joints was insufficient to hold unit together under normal usage. Maintenance in rejointing cost more than a new Holder was worth. The Brass Screw on each side had a tendency to loosen and fall out causing the sign to loosen and move out of position. Joints would also open if Holder was accidentally dropped off counter.	See Drawing — Due to hardness of plastic material, pieces of the Holder were actually broken off when it was accidentally dropped. Sections were of 1/8" and 5/32" thickness which was too thin to withstand this shock. Breakage was worse than in the wood type.	See Drawing — This type by far was the best of the three. Welded joints held up under all conditions of shock without affecting them in any way.
Weight and Stability	Weight 2 lb. helped to keep Holder fixed on counter when any of its contents was being removed. Closed flat bottom provided a good flat base.	Weight 1 lb 6 oz which was insufficient to keep Holder fixed by its own weight. Open construction of its base due to molding requirements (See Section on Drawing) provided very poor base area to rest on. It was later required to drill hole through base for fastening down to counter top — a very poor solution at that.	Weight 3 lbs. Holder remained fixed and did not move under normal use. Flat closed bottom provided excellent stability.
Refinishing	Removing finish and applying a new one costs about 50 cents per unit. This price does not include a new sign.	Although this type received final finish from the polished finish of the steel mold, its glossy surface could not be repaired after it had been marred while in service.	Removing the finish and applying a new one costs about 42 cents per unit. This price includes a new silk screened sign.
Appearance	Box like appearance showed need for room for improvement.	Thin sections required by this process forced up the design into too many parts.	Steel was only natural material available that would make design possible. Functional appearance.
Warpage	Constant problem especially if wood stock had been poorly seasoned. Joints opened up and loosened construction. Wood also had tendency to split.	Here again the required thin sections caused fine checks in the corners if the Holder was not properly cured after removal from the mold. These did not appear until Holder had been put into service.	Any warpage occurring was rectified at the manufacturer's before finish was applied. No other warpage later.

Hazards	Open grain wood such as oak often splinter along corners after being under hard use, causing a hazardous condition.	If kept in service with broken corners, any rough and jagged edges could cause scratches on the customer's hand.	All sharp corners were ground off and welded edges were ground to a small radius, eliminating any possible hazards.
Signing	A separate item, which required removing wood parts for installation. Replacing value about 25 cents each.	A separate item and installed with escutcheon pins at sign corners. Sign had tendency to bow out. Replacement unsatisfactory since same nail holes could not be used and new ones were necessary for each replacement. About 25 cents for each sign.	Sign is silk screened directly to Holder and was baked on. Replacing costs—12 cents each for lots of 25.
Color and Finish	Oak, Walnut and Mahogany. Paint was impracticable for wood Holders for our use.	Had wide choice of color but required lots of 500 to make this practical. Only one surface finish.	Full choice of color and baked finishes. For our standard use, the Holder was finished with a baked Tobacco Brown crinkle.
Cost of Model	Not available.	Could not make plastic model without using a mold.	Chrome plated model $25.00 each. Welded model $40.00 for one.
Cost in Production	1934 — Lots of 500 Unit Price $1.50	1937 — Lots of 800 Unit Price $1.19 1940 — Lots of 500 Unit Price $1.64	1941 — Lots of 1000 Unit Price $1.15
Saving with Welded Type (Comparison)			Saving per Unit over Wood—35 cents. Saving per Unit over Plastic—49 cents.
Percent Saved with Welded Type as Compared with Wood and Plastic			Percentage lower than Wood—22.3% Percentage lower than Plastic—39%
			There also was a certain amount of money saved on printed matter because the curved front helped it to retain its shape, thus making it usable for display for a longer period of time.

(Left to right): Fig. 1. Display holder, wooden type. Fig. 2. Display holder, plastic type. Fig. 3. Display holder, metal type. Fig. 4. Display holder, welded type.

Further Uses—This display holder while primarily designed for the use of telegraphic blanks, can also be used for the display of other types of printed matter, such as railroad time tables, air transport schedules, hotel reservations and for sales information for department stores

If built in size on a somewhat larger scale, current issues of magazines, tabloid newspapers, sheet music and similar items could be displayed in a neat upright manner without the wilted flower effect so many of them get after being on display for a short period of time

Conclusion—Our company has found that the process of arc welding has assisted our work in the following ways

1 It has helped us create a well styled commodity which has enhanced the display of our advertising matter

2 It has helped keep this material in good shape for a longer time than the older types of holder, thus saving some money when we discarded decrepit looking matter

3 It has been a vital factor in lowering the cost of the holders and yet, at the same time, making them more durable

4 It has helped eliminate those small personal hazards of splinters and scratches which have always been so objectionable from our customers' viewpoint

SECTION VII

Commercial Welding

Chapter I—Developing and Conducting a Commercial Welding or Job Shop

By FRED H. DREWES

Welding Engineer, W. P. Thurston Co., Engineers and Contractors, Richmond, Virginia

Fred H. Drewes

Subject Matter: A thorough discussion of all the items that should be considered in establishing and maintaining a shop.

Plant Layout, Design and Equipment—Erecting and equipping a new welding shop represents the largest single investment the average commercial welder will make in a lifetime. So out of respect to cost, if for no other reason, the undertaking demands thorough study. Every single item, large or small, deserves careful and deliberate planning. Each detail, no matter how insignificant it may first appear, contributes to the total cost of the undertaking. In the final analysis, it materially affects the efficiency, the economy, the coordination of the finished shop when the construction men withdraw and the equipment is put in motion.

Whatever may be the size or thoughts in regard to the intended shop, the small items should be watched from the start. Since the principal objective of the new shop, or as is often to be referred to in this paper as 'the new plant' because it is the new plant of the commercial welder—to fulfill a definite need, every single provision in the plans—every little item or detail—must contribute toward meeting that need.

Those in constant contact with plant layout and design discover that the safest way to avoid errors is to plan correctly from the very beginning. The starting point is the need for the new plant or shop.

First, it should be necessary to determine that the present shop—meaning machinery, equipment, and building—is worn out.

Second, establish that it is a fact that the business has outgrown present facilities and quarters and demands expansion.

Third, that it is a fact that the old shop and property are out-moded and consequently a detriment to future growth of the business.

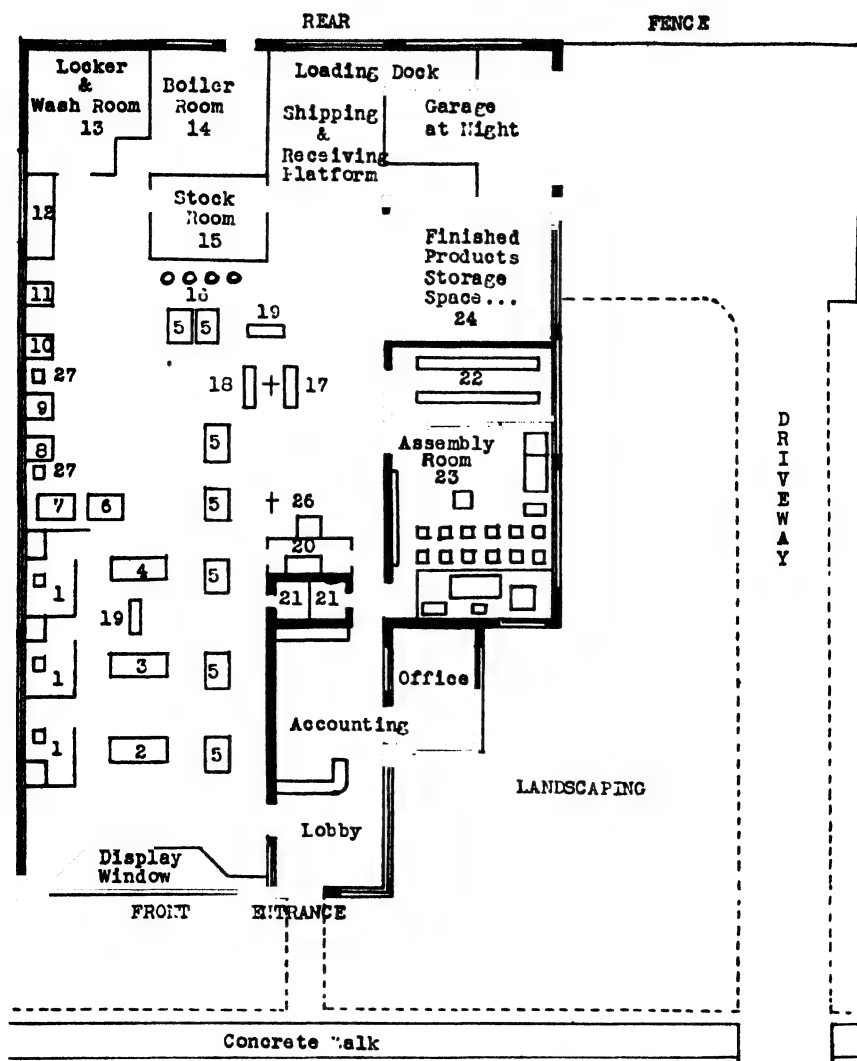



Fig. 1. Compact arrangement of job welding shop, main floor.

Having established that a new 'home' is necessary for the business, it should then be fixed in mind and on paper as to what type of building and where located to make for simplicity of operation, efficient and economical production. The routine, then, is one of seeking the counsel and assistance of. . . . First, capable minds within the industry whose duty it is to advise commercial welders and job welding shops for the specific purpose of improving and expanding present shops or building new shops. They are found among the equipment houses and manufacturers of the equipment used in arc welding. Second, capable architects who have had experience in and who have made a study of plans for job welding shops. An architect schooled in industrial plans such as those required for job welding shops is essential in completing the undertaking.

Selecting the Plant or Shop Site—After viewing the contemplated undertaking strictly from the practical angle, follow through from start to finish on the same practical plane. Select a number of possible sites for the location of the new shop. Analyze each one from every conceivable standpoint in relation to its contribution to the efficiency, economy and value to the business.

1. Is the site suitably located with respect to territory served? Is it near the center of distribution?

2. Is the plot of ground level, sloping, hilly, of good foundation, sufficiently large to permit future expansion and to permit present landscaping? Will it accommodate the type and size of shop desired?

Without forethought and careful planning, it is possible to spend $50,000 on a plant or shop and not have the shop that is wanted, while $30,000 will answer every single need if spent wisely. The degree of planning necessary must spring from the ground up—from the actual selection of site after needs have been defined.

There are other considerations essential to selection of the proper site and to the type of building conceived. For example both the proprietor and the architect must know such details as how many streets adjoin the lot. If two streets, where are they—one in front and one across the back? Or is it at an intersection? Is there an alley? What types of business are operated on either side and in the rear? What's across the street in front of the site? Is it a residence or a business? Is the site in a residential section or strictly an industrial zone? All these factors govern initial conception of the type of plant to be erected, and they have definite relation to the cost. There's one other consideration: When buying a new site, it is well to remember that the erection of the new plant will enhance the value of the surrounding property. The job welder is not in the real estate business, but if adjoining property is available at reasonable cost, often it is a good investment to tie it in with the purchase of the plant site. It can be sold off later at a profit.

City zoning ordinances should be examined before buying the property. There may be certain restrictions that would prove disastrous. The architect is probably familiar with zoning laws as well as building codes and insurance requirements, and the architect should be consulted on these points.

Planning the Building—After detail requirements have been provided for and the site selected, the next logical step is to commence planning the building. Here, too, the procedure is from the inside out, not from the outside in. Design and appearance come second. First, visualize the needs.

Visualizing the New Shop—The only proper way to arrange a positive conception of the undertaking is to work it out roughly on paper. Draw the lot lines, then fit the building into a given area within these lines. Indicate wall arrangements showing division of offices, the shop proper, storage spaces, and other desired arrangements. Indicate loading areas and openings. With colored pencil, spot the various pieces of equipment and machinery, showing spacing arrangements, working areas and aisle space.

The Movement of Materials—Having made the initial rough plans, the next step is to study the movement of materials into and out of the shop. Indicate on the plan the spot where they are to be unloaded, carried into and stored in the shop. If there is any congestion due to limited aisle space, this should be eliminated and will likely call for slight revisions in the plans. Any congestion causes delay in the movement of materials, and this delay slows down work in the shop.

Call in the Architect—The rough plan, naturally, cannot be turned over to a building engineer or contractor. It is time now to call in the architect, who is to work out details of the construction. A capable, trained architect is an essential at this point. He knows the suitability of construction materials, local building restrictions and requirements, and minute details of architectural engineering to such an extent that he can save money many times in excess of the fees that he will charge. The architect cannot be expected to interpret desires or problems of the individual job welder, therefore, it is important to lay before him complete details of the plans originally conceived for the type of building desired. He cannot be expected to be familiar with intimate peculiarities of the welding business, even if he has studied it, for each individual shop and job welder presents particular problems. Give him the rough plans and the benefit of full counsel. Caution him, guide him, and at the same time listen to the architect's advice. If the architect's plans are fitted specifically to the needs—the practical requirements—a coordinated plant will be assured.

Other Considerations—Now that the architect has been called in, the practical procedure cannot be dropped. A plant or shop that is to be a success from the construction angle requires follow-through on the part of the management, and this follow-through must be applied to numerous other considerations in order to guard against slip-ups in little details that will occur despite carefully thought-out plans initially. These other considerations are touched upon very briefly under the following subhead classifications:

Structural Frame—Reinforced concrete or steel may be used. With reinforced concrete, the columns and beams and girders are of poured concrete with steel reinforcing. Floor slab is concrete with clay tile in the offices. In the shop the floors are the same as for the concrete frame. In some of the smaller plants, roof framing is done with wood.

External Appearance—The building's external appearance should be in harmony with surrounding buildings. Regardless of location, certain fundamentals apply: Clean, neat appearance of the building; well landscaped yards and spic-and-span drives. Have a show window—show the public what's going on inside, behind a large plateglass window. These intimate details should be provided for in the final plans submitted by the architect. As to design, exterior walls may be of brick or a combination of brick and load-bearing tile. Regardless of the practical arrangements planned for departmental and mechanical coordination of the plant inside, the appointments can be made attractive and pleasing, and should tie in definitely with impressions conveyed by the external appearance.

Interior Finishes—For the shop, stock rooms and storage spaces, the floors should be troweled cement. The office portion of the building may be finished as simply or as elaborately as the owner desires. A happy medium for finishes in this portion of the building seems to be plaster walls and ceilings, terrazzo or asphalt tile floors, wood trim and wood doors. The owner's office may be paneled with wood, or Flexwood, at no great cost, and depends upon the owner's desires or tastes.

The proper location of the offices, so that they are easily accessible both from the street and from the interior of the shop, is not a difficult problem. If possible, the interior of the shop as well as other areas of the building, should be visible from the management's office through spacious windows. Sometimes it is advisable to arrange this visibility from the foyer, if one is provided, so that visitors may view the interior.

The lobby and general office may be one large room divided into units by high counters. A small fireproof vault adjoining the general office is desirable, and is relatively inexpensive. Extra office space, rest room facilities for office employees, and meeting room might also be provided. The assembly room should be large enough to accommodate every member of the organization, and should lend itself to meetings and classes.

One of the common faults in shop construction is failure to build the floors with proper slope and of proper material. Drains are essential. Floor drains complete with strainers and traps are preferable, the pipe having a diameter of 3 inches and constructed of extra heavy metal to resist corrosion. Adequate slope is essential to all drain lines so that stagnation may be avoided. Drains are preferable to gutters.

Walls and Ceilings—Clearance between machinery and walls and ceilings is important, and sufficient clearance must be provided for in the plans. All machinery and equipment must not be less than two feet removed from walls. Alleyways and working aisles between equipment and walls must be not less than three feet wide.

Location of Equipment—Proper location of equipment is important to the efficiency and economy of the plant. Correct placement with minimum lost motion between correlated units provides close control over handling operations and enables management to prevent cross traffic and avoid bottlenecks in operation.

OUR DESIRE IS

To serve with justice and integrity those whose property has been entrusted to our care.
To take no unfair advantage of our customers.
To support right principles and oppose bad practises in workmanship.
To develop character, ability and knowledge in our employees.
To value honor above profit.
Thus to be faithful to ourselves and to those we serve.

YOUR WELDING SHOP
1625 N. Main St.
DIAL 3-450

Fig. 2. Copy for sign board.

Heating, Plumbing, Ventilating and Electric Wiring—These items usually fall under the head of miscellaneous equipment. The heating of the shop is usually done with a low-pressure steam or vapor system. In some of the larger job welding shops closely allied or in the same building with a large machine shop, high-pressure boilers are used but a low pressure boiler will handle the majority of plants. Unit heaters, which are efficient and economical, are usually used in all spaces except in the office where radiators are usually employed. Some type of automatic firing should be used even in the small plants. This firing may be done with a mechanical stoker if coal is used, or an automatic oil burner if oil is used. Of course, if gas is used, the firing is automatic. The plumbing can give more trouble or more satisfaction than any other one item. To start the plumbing system right, use a large incoming line from the city main. Even the smaller shops should not use anything less than a two-inch line. Check the city water pressure and if found too great for ordinary fixtures, install a pressure reducing valve on the lines going to the ordinary fixtures.

Good fixtures and plenty of them are needed. A lot of time can be wasted around a shop by continually working on fixtures, and by employees waiting around toilets and locker rooms.

In water supply lines and heating lines, galvanized steel pipe, wrought iron pipe, copper or brass pipe may be used. Cast iron is used for sanitary sewer lines. The building codes should be consulted for weights and all requirements for plumbing.

The ventilating system is another part of the mechanical equipment that should receive careful attention. Provide sufficient windows for natural ventilation. Toilets, if placed inside, can be ventilated with rotary roof vents. If the boiler room is placed below grade, thereby eliminating window vents, a small fan can be installed in the boiler room to force the air out at any given point.

Every shop must provide for adequate wash room and toilet facilities. Provisions can easily be made in any completed plans for the necessities. Locker rooms or locker space for the shop men can easily contain toilet and wash room facilities, located off storage areas.

Loading Facilities—One of the weak points in plant and shop construction in recent years has concerned unloading and loading facilities. It is not uncommon to find a welder who is losing hard-earned money in lost motion in the distribution system simply because of lack of proper unloading and loading facilities. The movement should be straight-line, from unloading area to loading area, or from truck to platform level and then ramp to ground or floor level. No matter how small or how large the shop, facilities can be properly planned to save truck time, wasted motion, and eliminate cross traffic in the shop. The shipping and receiving platform should have a roof over it, and the edge of the platforms should have ½ of a 6-inch pipe embedded in the concrete at the point of pouring. This pipe forms a round guard that will not cut tires. Full consideration must be given loading and unloading provisions in the plans for the new building and 'home' for the commercial welder or job shop.

Drives and Garaging—The lay of the lot and type of building governs driveways almost entirely. One driveway employing one gate or opening both for entrance and exit is all that is necessary.

Garages may be divided into two main classifications—the individual garage and the group garage. The individual garage can be located apart from the main building in temperate climates where winters are not too

severe. The group garage, housing the trucks and other company cars in a common space, can be handled by erecting a large enclosed space at the rear side of the building. This space can be used as loading area and for the storage of trucks and cars as well. Spaces for repair shop can be cut off in a corner of this area. This system has the advantage of having the loading area, platform and garage enclosed which has proven an advantage in colder climates.

In estimating spaces for garages, allow a space of 10 feet by 30 feet for the average size truck. Of course, light pick-up trucks will require less space. If the garaging facilities are provided for under the roof of the welding shop proper, as is essential in some climates and sometimes preferred by the individual shop owner, ample space should be provided for turning and parking to avoid congestion. Adequate space also is important in the open yard in front of separate garage. The follow-through demands attention to every little detail, for easy maneuverability of trucks in and out of the shop makes for smoother distribution and more economical delivery. Correct depth of garage space between garage and main shop, and adequate provision for drives must be contained in plans for the undertaking. If only one driveway is afforded by the ground on which the building is to be erected, then this driveway should be sufficiently wide for the passage of two vehicles. Such minor details as rounded footings to corners of garage entrances, doorways and gateways, as guards against damage to fenders and the entrances, are essential in thorough planning. The average commercial welder has never had sufficient storage space since he traded the old horse and wagon

B E W A R E

Your doing business with us is the best insurance you can buy.

Beware of any person who tries to influence you to take your business to some other company; as the only one to profit by such a change would be the other fellow - - not you..........................

Insist on consulting us before taking any action. Get his proposition, then call upon us for information and counsel, which will be freely and gladly given...........

YOUR WELDING SHOP
1625 N. Main St.
DIAL 3-450

Fig. 3. Another sign board suggestion.

for a motor truck, and substituted real outdoor advertising in place of calendars. And in the beginning, he never dreamed of the modern bar racks and arc welders and quenching tanks. Consequently in the new shop, he should resolve to secure ample storage space for materials and equipment. In the writer's conception of a modern small job shop building handling a general line of job welding, the 1-story building, strictly modern in design, has neither basement nor second floor. Some of the finished products are intended to be displayed behind the large window in the left foreground, as well as providing a general view of the main shop to the passer-by and also to afford ample light and ventilation.

Fig. 1 is a floor plan of the small job welding shop. Compactly arranged, this set-up permits smooth movement of materials and finished goods. Garaging and loading platform are combined in right rear. This plan, of course, is variable.

The Equipment Needed—Shop facilities must obviously be provided if an acceptable and profitable job welding shop is to be presented. Quite naturally any plan such as shown in Fig. 1 is of a tentative nature and must be adapted to existing buildings and facilities unless the business is located in a new building especially constructed, such as the plant layout and design previously referred to. The present extent and arrangement represents an average layout consistent with budget limitations. In establishing a commercial welder or job shop, it is perfectly feasible to install only one piece of equipment in each of the departments listed and still have a well-balanced shop.

The following list of equipment is broken down for detail consideration and it should be emphasized here that although this layout represents a hypothetical laboratory or shop, the general arrangement and organization is the result of actual experience in planning and using this layout. For this reason due consideration should be given major departures from the arrangement shown. Following is a detailed list of the equipment shown in the plan and directly following this will be found a discussion on 'the electric arc' together with a study of the arc welding generator capable of doing every job that comes into the shop.

LIST OF EQUIPMENT

Metallographic: Micro Camera, Microscopes, Polishing Wheels, Belt Grinders, Grinding Wheels, Dark Room Equipment.

Arc Welding Equipment: Single Operator M.G. Set 200-A, One Arc Gasoline Engine-Driven Railer Model 300-Amp., A.C. Transformer, 2 Welding Tables, 2 Welding Booths, 2 Screens or Shields.

X-Ray Equipment: Low-Voltage Machine (capable of penetrating 1-inch Plate).

Physical Testing: Portable Tensile and Bend Testing Machine, Hydraulic Tester.

Machine Tool Equipment: Power Hacksaw, Milling Machine, Surface Grinder, Bench Lathe.

Resistance Welding Equipment: Automatic Flash Welder, 35 KVA Spot Welder.

Oxy-Acetylene Equipment: Hand-Cutting Torch, Automatic Straight Line Cutt. Mach. equipped for Flame Hard., Welding Torch with Cutt. Attach., One set of Regulators, Oxygen Cylinders, Acetylene Cylinders or Acetylene Generator, Set of Cutting Tips, Set of Welding Tips, Set of Cutting Attachment Tips.

Accessories: Electrode Holder, Wire Brushes, Chipper Hammer, Fibre Helmet, Fibre Hand Shield, Welding Gauntlets—Leather and Asbestos, Welding Goggles, 2 50 ft. Lengths Hose or 1 50 ft. Length Twin Hose, M.S.A. Speedframe Goggles, Welding Gauge, Fume Collector.

Power Supply: 110-Volt A.C. (Single Phase), 220-Volt A.C. (Three Phase), 110-220 Volt D.C.

PROFIT & LOSS STATEMENT

PERIOD ______________________ DATE ______________

No.	Item		
1.	Total Sales For Month (or Week)		$______
2.	Less Mdse Returned		-______
3.	NET SALES		______
4.	Invty.at Beginning of Month (or Week)		
5.	Net Mdse.Purchases for Month(or Week)	______	
6.	TOTAL	______	
7.	Deduct Invty.at end of Month(or Week)	-______	
8.	Cost of Mdse. Sold		-______
9.	Gross Profit on Sales		______
10.	DEDUCT: Truck Expense	______	
11.	Freight & Drayage	______	
12.	Salaries	______	
13.	Overhead (Rent,Light,etc.)	______	
14.	Losses from bad A/c's	______	
15.	Other Expense ______	______	
16.	Other Expense ______	______	
	TOTAL OPERATING EXPENSE		-______
	ADD: Any other income______	______	
	Any other income______	______	+______
	NET INCOME FOR MONTH (OR WEEK)		$______

Fig. 4. Profit and Loss statement.

Miscellaneous Equipment: Air Compressor or Compressed Air Cylinders, Plate Storage Rack, Bar Rack, Steel Work Bench, Steel Stools, Shoprobe (Clothes Storage Unit), Tool Stands, Tool Cabinets, Steel Desk for Welding Foreman, Parts and Supply Bins, Steel Tool Crib, Stock Cart, Steel Folding Chairs, Quenching Tanks, Lantern Slide Projector.

The foregoing list of equipment is offered with one fact kept uppermost in mind, namely, the material and layout to assure a fair profit to the owner of the business is the major consideration and anything else is secondary in importance.

When a shop starts to expand, it is some time before there is a full realization on the part of the management that the shop has grown beyond the old shop lay-out. A good deal of cost and confusion will be eliminated through prompt reorganization and perfected lay-outs.

In initiating work on a production basis, it should be borne in mind that additional facilities should be added to facilitate operating on a mass or production basis, for example, a complete designing or drafting room should be added in order that the product may be designed or checked in a preliminary way before the job is accepted, and to make the detail drawings before the job is accepted in the shop.

These detail drawings should contain all information including the type of steel, the type of weld, the type of welding rod and any other information that the shop might desire. The drafting room should understand to a fair extent the shop procedure in building the product. The checker of the drawings should be thoroughly versed in every operation that the product takes through the shop because it is primarily the design and secondly the cost of fabricating that will obtain or lose a job. The checker should then

DATE ________				
DAILY RECORD OF SALES BY COMMODITIES				
COMMODITY	UNIT (CU.FT.) LBS. EA.	GROSS SALES	MDSE. RETD.	TOTAL NET SALES PER DAY
APPARATUS (Elec) (Include Machines)				
APPARATUS (GAS) (Include Machines)				
SUPPLIES (ELEC)				
SUPPLIES (GAS)				
GASES: OXYGEN				
GASES: ACETYLENE				
GASES: ________				
CARBIDE:				
ANY OTHER SALES ________ ________				
TOTALS:				
TOTAL: Same Day Last Week				
TOTAL: Same Day Last Month				

Fig. 5. Daily record of sales by commodities.

take the prints to the shop foreman or production engineer, and go over the drawings completely with him so that the foreman or engineer can provide room in the shop and set the delivery date. The drawings are then turned over to the head welder or lay-out man in the shop.

The layout man must have stock to work with. It is his duty to keep a record of this stock for re-order when it becomes necessary or when it becomes close to being used up, and it is also important that he use the steel most economically to prevent excessive waste. He must stock the necessary plate on the basis of the most suitable thicknesses for the class of work handled. He should also see that a stock of round bars is carried in various sizes. The stock should also include standard size channels, I-beams and angles, and the necessary stock of different size welding rods and electrodes.

The layout man must have the necessary tools for doing layout work

on steel and other metals, must be thoroughly familiar with reading blueprints and the way in which the job is built. A layout man in very many cases can see something on the drawing that should be changed to reduce the cost of construction and still keep the job as strong as it should be. He should have the information on the drawings as to what the machine or part is to be used for so that he may get an idea as to whether the job is primarily intended for strength or beauty.

For example, we will suppose a job was to be used as a machine base with most of the base buried in concrete; if the layout man did not know that this job was to be used for strength, he would very likely order the corners to be ground off to make it beautiful. He must also be familiar with machine shop practice so that he will know how much to allow in different locations for cleaning up or machining.

From the layout man, the job goes to the cutters or burners. However, the layout man must be in complete charge of the job from beginning to end and made responsible for the completed article. After it is tacked together it is ready for the actual welding. After the job is completely welded it is ready to be machined unless it should be sand-blasted first in which event the paint is applied at this point. The product is then ready to send over to a machine shop for the final machine work.

In some instances following the complete welding of a product it is placed in an annealing furnace to bring about a more perfect job. In such cases, the annealing furnace should be capable of heating the object to at least 1200° slowly and uniformly. Several jobs are designed in such a manner that warpage takes place to quite an extent while welding and the annealing furnace can be used not only to take the strains out but by leveling the

SALES LEDGER

DATE	SOLD TO:	CASH SALES		CHARGE SALES		MDSE. RETD.	

Fig. 6. Sales ledger.

job up and weighing down, it can be used as a straightener and still leave no stresses in the finished product. The smaller job shop will find it more profitable to send the product out to be annealed, particularly if the demands for this finish in a product is not too great. The larger commercial welder or job shops should install annealing furnaces capable of taking care of the greatest size job that would in all probability ever be made in the shop.

KEY TO FLOOR PLAN OF SMALL WELDING SHOP

(See Fig. 1)

NOTE: Space on Floor Plan does not permit detailing by name, hence the numbering system herewith presented for ready identification:

1. Arc Welding Booths
2. 300 Amp Arc Welder
3. 200 Amp Arc Welder
4. A.C. Transformer
5. Welding Tables
6. Automatic Flash Welder
7. 35 KVA Spot Welder
8. Surface Grinder
9. Milling Machine
10. Power Hack Saw
11. Belt Grinders
12. Steel Work Bench with:—
    Grinding Wheel
    Bench Lathe
    Vise
13. Locker and Wash Room with:—
    Usual Facilities
    Shoprobe (Clothes Storage Unit)
14. Boiler Room
15. Stock Room with Parts & Supply Bins for:—
    Apparatus for Resale
    Supplies for Resale
    Apparatus for Consumption
    Supplies for Consumption
16. Oxygen & Acetylene Cylinders
17. Air Compressor
18. Tool Cabinet
19. Quenching Tanks
20. Welding Foreman's Office, contains:
    Office Equipment with:
    Steel Desk
    Steel File Cabinet
    Suitable Chair
21. Rest Rooms with Usual Facilities
22. Plate & Bar Storage Room with:—
    Plate Storage Rack
    Bar Rack
23. Assembly Room, contains:—
    Metallographic Equipment
    Dark Room Equipment
    X-Ray Equipment
    Raised Platform with Desk & Chair
    Portable Tensile & Bend Test. Machine
    Hydraulic Tester
24. Finished Products Storage Space
    Blackboard on Left Wall
    Projection Screen in Front of Rear Wall
    Projector in Center of Room or from Raised Platform
    Press & Sink in Front of Right Wall at Window; also Polish Wheel
    12 Steel Folding Chairs in Front of Raised Platform
    Specimen Cabinets & Display Board where Space Permits.
25. Steel Tool Stand
26. Steel Stools

Advertising—If one force is sadly lacking in retarding the forward pace of job welding in the welding industry today, it may be truthfully stated that it is due to the lack of or improper advertising.

Sales and advertising effort must be correlated in any business if maximum effectiveness is to be expected. In only the largest commercial or job welding shops are there separate advertising and sales departments. Even then, sales and advertising are closely related and associated through the general management. In the average job welding shop the individual charged with sales is generally also in charge of advertising.

Outside agencies often handle details of the advertising programs but the final approval of the company's advertising effort rests with someone in the shop closely related with the sales department. It would be extremely difficult to discuss operations of the sales department without simultaneously taking into consideration its relation to advertising effort. The theme of advertising and the theme of merchandising should be identical at all times.

And, just as merchandising should be carried on with consistency, advertising effort must be carried on in the same way.

Important Role—It is agreed that the first rule of advertising is consistency. A rule of almost equal importance is that advertisements should follow a definite theme.

A theme cannot be developed through occasional advertisements. There is no such thing as impression of a theme with a big splash run for a short period and then forgotten. A theme must be sold through repetition, with a different appeal to get the theme over. As an illustration, a recent series of advertisements featuring a nationally advertised bread used the "try it" theme. The purpose of the campaign was to get consumers to try the bread. Without a great deal of copy but with attractive illustrations, this theme was pounded for a solid year. The loaf of bread was displayed in every advertisement, but the main illustration had no relation to bread whatsoever. For instance, a little girl was shown hanging from her knees on an acrobatic bar. The theme was "try it". The inference might be that the consumer was being sold to try hanging from the knees on an acrobatic bar but anyone could tell that the idea of the advertisement was to get the idea of the advertisement over to the consumer to try the bread. Consistent use of that theme throughout the campaign brought marked results in new customers.

When an advertising campaign is being planned, money available for advertising purposes should be budgeted carefully. The money should not be spent in one big splurge. On the other hand, it is unwise to spread it out so thinly that it is not effective. The advice of advertising council in the allotment of this money is helpful and will avoid waste.

Advertising Rules—Certain rules apply to advertising that should not be overlooked by the job welder if he is to get maximum effect from his advertising dollars.

The rules are:

1. Select a theme and stick to it throughout the campaign.
2. Repeat the theme in all copy from as many angles as possible.
3. Spread the budget on a planned, controlled basis.
4. Use advertising media known to give the largest possible returns on the money.
5. Unite merchandising and advertising effort behind the theme.

Related Media—In discussing the fundamentals of good advertising it will be necessary to first treat the budget and then to discuss the various media which are used by the job shop welder and their relative importance.

The Budget—Two factors control the amount of money a job shop should set up for its advertising expenditures. The first is the need for advertising expenditures. The second is the welder's ability to pay for his needs. These two questions must be answered before any intelligent approach to the advertising program can be made. The answer to the first must depend upon many other factors. Consideration must be given to such problems as:

1. To what extent does the product have public acceptance?
2. To what degree has the maximum potential of the market been reached?
3. How competitive is the market?
4. What is the trend of competitive job welding shops and what is the competitive job welder doing to better his position in the market?
5. Is the job welder convinced that his sales effort is carrying its share of the burden?

DAILY CASH RECEIPTS & DISBURSEMENTS (Cash and Checks)

RECEIVED				DISBURSED							
Date Rec'd.	From:	From Cash Sales	From Charge Custo-	Date Paid	To:	Amt. Paid $	Truck Exp. $	Freight & Dray-age $	Sal-aries $	Light Rent Heat ETC. $	BANK DEPOSIT $

Fig. 7. Daily cash receipts and disbursements.

It is apparent, of course, that answers to those questions would be entirely different if asked of the manager of a new job welding shop entering a market, and then asked of the manager of an established plant with an established volume. In either case, however, three points should rule.

First—the advertising budget should be prepared in advance of the expenditure of any money and its allocation to the seasons of the year should be stipulated.

Second—consistent plugging of the advertising theme should be provided for and funds should be available at whatever time they are needed.

Third—the only sound basis for planning an advertising program is to base the programmed expenditure on a combination of previous sales and sales potentials.

The factor of need for advertising, then, is of primary consideration, whether the shop be established or new. Naturally, the need will be greater for the plant without established consumer demand and public acceptance of the product.

The new shop has a three-fold job. First, its advertising must be designed to hold consumers already secured. Secondly, its advertising must be designed to win away from other products customers who will increase consumer acceptance. Thirdly, its advertising must be designed to create new customers.

The established shop has only a two-fold job. First, it must hold its customers. Second, it must attempt to create new customers. The expenditures required for the established shops, therefore, are smaller than those of the new one. In consideration of that question of need for advertising, the new shop finds its requirements far greater, though—it is often the case—less able to pay for requirements.

With the new job welding shop and the old alike, the size of the market has a great bearing on the size of the budget required for advertising. The larger the market, the larger the percentage of sales necessary to reach it. Diversified population and classes of industries to be approached from different angles and the necessity for the use of more types of media cause this condition.

Source of Finance—Only two possible sources are available for funds required to carry out the advertising program. One of these is the shop's income. The other is the company's capitalization. If the former will supply the demand for funds, the latter should not be considered. If it will not, the latter must be called upon. The established job welding shop should never have to go into its capital for advertising. The new shop should expect such a situation. With an established business, a chart of sales expectations should be prepared and constantly checked. If plans are laid on the basis of such a chairt, expectations must be met or the entire advertising budget will collapse.

In the case of a new job shop it is not advisable to set a percentage of sales to be put into advertising. Rather, the owner or manager should arrange to take care of obligations, give himself the necessary money to live on and put all the rest into advertising. No profits should be taken during the period of market entrance.

Seasonal Advertising—As long as job welding sales vary with the season, all advertising authorities suggest that the expenditures from the budget shall be made in proportion to the volume of sales. The volume of the industry is greatest during the second and third quarters of the year, tapering down on the fourth quarter and reaching its bottom in the first quarter of the next year. Therefore, advertising appropriations should be set up to spend two-twelfths during the first quarter, three-twelfths during the second quarter, five twelfths during the fourth quarter and two-twelfths during the third quarter. There may be some variations from this in some markets, but this division is recommended as a rule in most cases.

The public forgets. Advertising reminds. Advertising has helped the welding industry. It will take advertising to further develop it and advertising costs money. Money must be budgeted for advertising in any successful job welding business.

Advertising Media—The various media to be used by the commercial or job welding shop in advertising necessarily must be selected with respect to the available money. With a limited advertising budget the job welder wants to use only the media that directly produce sales. As the advertiser expands his budget he will spread to other media. Rules that apply to job welding shops might not apply to any other business, though some related concerns will operate under similar rules.

Superior Media—Advertising that catches the eye of the prospective purchaser or user of the service and sells him at the time he is in the market is the most desirable form of advertising. For that reason, point-of-purchase advertising is far superior to any other media available to the job welder. Many advertising authorities feel that all other forms of advertising should "lead" the prospect to the outlet, and that advertising at the point of purchase should clinch the sale. In order of importance, the various media are:

1. Point of purchase.
2. Shop and window displays.
3. Outdoor bulletins.
4. Theatre screen advertising.
5. Radio advertising.
6. Newspaper advertising.
7. Novelty advertising.

Conditions in various markets may place one medium before another in importance, but certainly from point of purchase through outdoor advertising the order of importance will remain constant in any market. If billboard advertising sells the prospect, he will again be reminded of the product at the outlet by a window display. All of this is based on theory—an accepted theory of advertisers—that the closer the customer is to the point where he can exercise his impulse to buy, the greater is the effectiveness of advertising.

A primary rule in the selection of media is this: Exhaust every possibility of point-of-purchase advertising before spreading to other media. The cost of media must be considered, too. Point-of-sale advertising is less expensive than other forms. Outdoor advertising is next, and the cost of other media will probably follow in line of importance. Some discussion of each of these various types of media would be advisable. In the following pages

will be found a synopsis of the points in favor of and against each medium previously mentioned.

Point of Purchase—Point-of-purchase advertising includes printed signs, window strips, lithographed cards, and the like, but it extends to counter, floor and window displays of the products themselves. So, advertising opportunity in the outlets is quite varied. The selection of advertising for specific outlets and purposes should be done judiciously.

The welder wants a picture which will lend tone to his place but he does not want one which would be objectionable to any of his customers. Point-of-purchase material must be decorative and convincing to sell the consumer. Too much copy kills it. The copy used must be clear and used to repeat the theme of the rest of the advertising. A slogan or catch phrase is the best copy for point-of-purchase advertising. If it is a repetition of the theme of the welder's advertising and if it is perfectly clear in its meaning, it is good copy.

Five good rules apply to point-of-purchase advertising:

1. Do not hesitate to consult a specialist in sign-making.
2. Design signs different from those of the competitor.
3. Locate signs in the office, show windows and shop so as to please the consumer, not the sign painter or welder.
4. Have a variety of signs to meet the requirement of all work handled.
5. Make signs to sell and not be purely decorative.

In this connection it is well to have two general signs prominently 'spotted' outlining the policies of the business and stressing the need of continuing to do business with the concern. Two excellent suggestions are offered in Fig. 2 and Fig. 3.

Getting Established As a Dealer for Apparatus and Supplies—The progressive job welding shop today supplements its earnings and revenue with the carrying of a complete well established line of apparatus and supplies used in both the gas welding and arc welding field for resale.

A great majority of manufacturers of equipment today offer restricted territories under a signed "Authorized Dealer's Agreement". Usually separate agreements are drawn and entered into for the distribution of gases and electrodes. Electrodes are usually sold on what is termed an "Electrode Blanket Order Contract". There is no standard form of Authorized Dealer's Agreement for the distribution of gases.

A complete but inexpensive bookkeeping system, with full instructions may be obtained from the publishers, Wilson-Jones Company, for use of dealers, however, the sheets, Figs. 4, 5, 6, 7, 8 and 9 will provide an inexpensive bookkeeping system for the dealers' needs. The forms are provided with their explanatory notes to provide a guide or outline to work from.

Standard ledger sheets or columnar work sheets—obtainable in any stationery store—will be suitable, if the columns are "headed" as shown in the specimens. Large companies maintain complete accounting systems. Already established dealers may not need this "help" but it is felt that the specimen sheets will prove of real value (1) in establishing a new dealer, (2) by the small dealer with a "hit or miss" set up, or (3) by the itinerant dealer who may be a good salesman—but is not such a good business man.

In the sale of arc welders and torches and regulators it is well to keep in mind the proximity or location of the factory to which equipment may be returned for repairs or reconditioning. Many a sale is 'lost' because of the jobber's inability to secure prompt repairs or replacement of equipment

ACCOUNTS RECEIVABLE

NAME OF CUSTOMER ______________________________

DATE		AMOUNT OF SALE		BALANCE		AMT. OF PAYMENTS REC'D.			DATE

Fig. 8. Accounts receivable.

due to great distances from the manufacturer of the equipment the jobber is distributing.

Process Applications and Promotions—Herewith are presented some typical commercial welder or job shop customer operations by industries to encourage and stimulate the management of the commercial welder or job shop to apply the process of arc welding, from which more work and greater profits will result:

Bakeries: Repair Baskets (wire); Bins, Boxes and Containers (Fab. and Rep.); Bread Machine Castings made of Aluminum (Rep.); Conveyor Rings (Rep.); Cake Mixer Machines (Rep.); Dough Beaters (Rep.); Dough Mixers (Rep.); Copper or Monel Mixing Bowls (Rep.); Pans (Rep.); Racks (Fabricate or Rep.); Slicing Machines (Rep.); Storage Tanks (Rep.); Vats (Fab. and Rep.); Wrapping Machines (Rep.).

Boiler and Tank Shops (see also Power House Section): Boiler Feed Pump Casing and Housing (Fab. and Rep.); Boiler Draft Control Casing and Housing (Fab. and Rep.); Boiler Tube Cleaners (Rep.); Boiler Water Circulators (Fab. and Rep.); Furnaces (Rep.); Furnace Fire Door and Frame (Rep.); Pipe and Pipe Fittings (Fab. or Rep.); Water Tanks (Steel) (Rep.).

Brick Yards: Auger Machine (Hardface); Bearings (Steel) Hardface and Build Up; Brick Car Truck Carriage (Fab. or Rep.); Clay Cutters (Hardface); Clay Feeder Shoes (Hardface); Dipper Teeth (Hardface); Discs for Cutting Refractories (Fab.); Jarring Bars (Hardface); Mixer Blades (Hardface); Mud Screw (Hardface); Plug Mill Knives (Hardface); Pulverizers (Hardface); Roll Mill Crusher Plates (Hardface); Thrust Collars (Hardface); Trip Dogs (Hardface).

Chemical Industries: Filter Screens (Fab. and Rep.); Flanges (Fab. and Rep.); Guards (Fab. and Rep.); Screen Frames (Fab. and Rep.); Tanks and Vats (Fab. and Rep.).

Coal Dealers: Bins, Boxes and Chutes (Fab. and Rep.); Conveyor Bucket Lips (Fab. and Rep.); Heater Tube Pipes (Fab. and Rep.); Hopper Lips (Fab.); Loaders (Fab.); Scale Parts—Pivots (Hardface); Truck Braces (Fab. and Rep.); Side and End Sheets for Unloading Coal (Fab. and Rep.).

Contractors: Anchor Buoys (Fab. and Rep.); Dredge Pipe (Rep.); Cable Drills (Hardface); Caisson Digger Cutter Beads (Hardface); Crusher Jaws (Hardface); Dredge Cutter Knives (Hardface); Dredge Buckets (Hardface); Plate Girders (Fab. and Rep.); Latch Bars (Hardface); Pile Driver, Wearing Parts (Hardface); Post Hole Diggers (Hardface); Sand Blast Nozzles (Hardface).

Dairies: Bottling Machine Cams (Hardface); Cheese Hoppers and Buckets (Fab.); Conveyor Equipment (Hardface); Cream Separator Spouts (Weld On); Filter Screens (Fab. or Rep.); Floor Plates—Steel (Fab. or Rep.); Ladle Pail Hooks (Rep.); Milk Dryers (Fab. or Rep.); Sink Frames (Rep.); Stands (Rep.); Tanks, Vats (Fab. or Rep.); Truck Trailor Hitches (Hardface); Vacuum Tank, Propeller Blades (Rep.).

Electrical Equipment (Manufacturers and Repair): Circuit Breaker Boxes (Fab. or

Rep.); Housings (Fab. and Rep.); Shafts—worn (Rep.); Switch Boxes (Fab. and Rep.); Tranformer Hangers (Fab. or Rep.).

Farm Equipment: Binders, Conveyor Pulleys (Fab. and Rep.); Beet Puller Points (Hardface); Binders, Cycle Bars (Fab. and Rep.); Cane Shredder Blades and Knives (Hardface); Cattle Stanchions (Fab. and Rep.); Cisterns (Fab. and Rep.); Chop Axe (Hardface); Corn Planter Shoes and Runners (Hardface); Corn Shredder Tips and Knives (Hardface); Corn Stalk Cutter Blades (Hardface); Cultivator Sweeps, Points and Spades (Hardface); Cultivator Shovels and Spring Teeth (Hardface); Disc Cultivator Blades (Hardface); Drills—Seed (Hardface); Pulverizer Hammers and Knives (Hardface); Food Choppers (Hardface); Furrowing Shovels (Hardface); Hay Fork (Hardface); Hay Hammers or Cutters (Hardface); Hay Saws—Circulator—Teeth (Hardface); Harrow, Disc Blades, Bar Points (Hardface); Harrow, Gears (Hardface); Harrow Shovels and Teeth (Hardface); Headers (Hardface); Horse Shoes (Hardface); Leveller Blades (Hardface); Lister Shares (Hardface); Manure Handling Equipment (Hardface); Mower and Shoes (Hardface); Mill Hammers (Hardface); Nozzle Discs—Spraying (Hardface); Planters (Hardface); Plow Points, Shaves, Bar Points, Discs (Hardface); Post Hole Diggers (Hardface); Potato Diggers (Hardface); Pruning Shears (Hardface); Rakes, Eccentric, Roller, Trip (Hardface); Rooter Teeth (Hardface); Scrappers (Hardface); Scooter Blades (Hardface); Septic and Sewer Tanks (Fab. and Rep.); Stands (Fab. and Rep.); Subsoiler Foot Point and Teeth (Hardface); Threshing Machine, Concave Teeth (Hardface); Tractors—Cleats (Hardface); Treaders (Hardface); Wagons, Clevises, Bar Irons (Fab.); Water Troughs (Fab. and Rep.).

Flour and Feed Mills: Alfalfa Mill Hammers (Hardface); Augers (Hardface); Chute Bends (Hardface); Clutch Face (Hardface); Corn Knives (Hardface); Fan Blades (Hardface); Grinder Screws (Hardface); Grinding Hammers (Hardface); Hammer Sides (Hardface); Hay Mill Hammer Sides (Hardface); Pulverizer Blades (Hardface); Pulverizer Knives (Hardface).

Food Canning, Preserving and Packing Plants: Cams and Knockout Fingers (Hardface); Bone Mill Hammers (Hardface); Chain Links—Conveyor Equipment (Rep.); Chutes and Bends (Rep.); Crushing Mill Knives (Hardface); Forming Dies—Can (Hardface); Grinders (Hardface); Pipe and Pipe Fittings (Rep.); Sink Frames (Fab. or Rep.).

Forge Shops: Annealing Boxes—Steel (Fab. and Rep.); Anvils (Hardface); Doors, Water Cooled (Fab. and Rep.); Drop Hammer Die Blocks (Rep. Worn); Furnaces, Steel (Fab. and Rep.); Wheels—Steel (Rep.).

Foundry: Annealing Boxes (Fab. and Rep.); Castings—Defective (Reclaim); Charging Box, Car Wheels—Worn (Build Up); Coke Pusher Shoes (Hardface); Conveyor Dogs (Hardface); Core Machine Flights (Hardface); Exhaust Fans (Hardface); Ladles, Rail Hooks (Hardface); Ladles (Hardface); Mixer Blades (Hardface); Pump Housing—Sand (Hardface); Pump Housing (Pump) (Hardface); Sand Core Cutters (Hardface); Sand Plows (Hardface); Sand Revivifier Paddles (Hardface); Shovel Teeth on Tips (Hardface); Slinger Cups on Tips (Hardface); Vibrator Frames (Hardface).

Heating, Plumbing, Air Conditioning and Ventilating: Bases (Fab. and Rep.); Boilers (Fab. and Rep.); Fans, Bases, Blades (Rep.); Frames and Supports (Fab. and Rep.); Headers and Tubes—Steel (Fab. and Rep.); Pipe and Fittings—Steel (Fab. and Rep.); Brackets for Pipe and Hangers (Fab. and Rep.); Register Frames (Rep.); Screen Frames (Fab. and Rep.); Stacks (Fab. and Rep.); Stands (Fab. and Rep.); Stoker Hoppers—Wearing Parts (Hardface); Tanks, Oil, Water (Fab. and Rep.).

Homes: Andirons, for Fire Places (Fab. and Rep.); Bins, Boxes, Containers (Fab. and Rep.); Cabinets (Fab. and Rep.); Clothes Drying Racks (Fab. and Rep.); Fences (Fab. and Rep.); Furniture (Fab. and Rep.); Garden Tools, Mower, Hoe, Spade, Rake (Fab. and Rep.); Gates (Fab. and Rep.); Ornamental Iron (Fab. and Rep.); Sink Frames (Fab. and Rep.); Tools and Chests (Fab. and Rep.); Toys, Bicycles, etc. (Rep.); Water Pipes, Iron and Steel (Fab. and Rep.); Window Boxes (Fab. and Rep.).

Hospitals, Hotels, Restaurants: Beds, Frame (Fab. and Rep.); Bins, Boxes, Containers (Fab. and Rep.); Cabinets (Fab. and Rep.); Doors, Fire Door (Fab. and Rep.); Floor Gratings (Fab. and Rep.); Furniture, Metal Tables, Chairs, etc. (Fab. and Rep.); Guards and Covers (Fab. and Rep.); Heat Exchanger (Fab. and Rep.); Railings and Grilles, Ornamental (Rep.); Sinks and Frames (Fab. and Rep.); Tanks and Vats (Fab. and Rep.); Trucks for Moving Food from Kitchen to Dining Room (Fab. and Rep.); Wheel Chairs and Tables (Fab. and Rep.).

Laundries and Cleaners: Blowers, Housings (Fab. and Rep.); Boilers (Fab. and Rep.); Bins, Boxes, Containers (Fab. and Rep.); Clothes Drying Racks (Fab. and Rep.); Clothes Pressing and Ironing Machine (Rep.); Dry Cleaning Machinery—Stainless Steel (Rep.); Laundry Machine—Stainless Steel (Rep.); Pipes and Fittings (Fab. and Rep.); Tanks and Vats (Fab. and Rep.).

Machine Shop: Belt Shifter and Clutch Throwout Finers (Hardface); Bolt and Nut Machine, Guide Rolls (Hardface); Boring Bar, Wearing Strip (Hardface); Cam Ejector Pins (Hardface); Cams and Rocker Arms (Hardface); Chain Links and Pins (Hardface); Chuck Fingers (Hardface); Clutch Fingers and Tripper Jaws (Hardface); Cranes and Crawlers—Frame (Fab. and Rep.); Cranes and Crawlers, Contact Shoes (Hardface); Drill Chucks, Worn Holes (Hardface); Grinder Rests (Hardface); Lathe Centers (Hardface); Lugs, Tool Posts and Blocks (Hardface); Machinery, Bases, Frames, Guards, Covers (Fab.); Machinery—Wearing Surfaces (Hardface).

Municipal (City) Equipment In Connection With Parks, Streets, Etc.: Ditch Digger Sprockets and Gears (Hardface); Ditch Digger Teeth (Hardface); Paint Guards (Hardface); Power Mower Shoes (Hardface); Street Scrapers (Hardface); Street Sweepers (Hardface); Smoothing Irons (Hardface); Spreaders (Hardface); Traffic Signals—"Stop and Go" (Rep.); Repair Bins, Boxes, Containers (Fab. and Rep.); Calking Tools (Hardface); Cinder Loader Blades, worn (Hardface); Sewage Ejectors (Hardface); Sewage Impellers (Hardface); Tamping Bars (Fab.); Water Tanks (Fab. and Rep.).

Power Houses: Ash Conveyor, Drag Line and Link (Hardface); Ash Crusher—Knocker (Hardface); Expeller, Multiple Set (Hardface); Ash Hopper (Hardface); Cams, Lifter and Valve (Hardface); Cinder Loader, Fan Blades (Hardface); Coal Conveyor Buckets (Hardface); Coal Conveyor Bucket Lips (Hardface); Coal Conveyor Chain Links (Rep.); Coal Crusher Equipment—Segments (Hardface); Coal Feed Dogs (Hardface); Coal Feeder Screws (Hardface); Coal Pulverizer Hammer (Hardface); Coal Pulverizer Mill Bull Rings (Hardface); Coal Pulverizing Mill Plows and Tips (Hardface); Coal Pulverizing Mill Yokes (Hardface); Drip Valves, Poppet Style (Hardface); Fan Housings—Draft (Hardface); Fan Blades (Hardface).

Refrigeration: Ammonia Accumulators (Fab. or Rep.); Ammonia Cooling Coils—Steel (Fab. and Rep.); Condensers (Fab. and Rep.); Containers (Fab. and Rep.); Flangers (Fab. and Rep.); Guards, Railings, Covers (Rep.); Ice Conveyor System Guides, Rollers, Treads (Rep.); Pipe, Coils and Fittings (Fab. and Rep.); Refrigeration Box and Cover (Steel) (Rep.).

Sand, Stone and Gravel Pits: Cable Drills (Hardface); Chain Links and Pins (Hardface); Conveyor, Bucket Lips (Hardface); Crusher Jaws, Plates (Hardface); Dipper Lips (Hardface); Dipper Teeth (Hardface); Drag Line Buckets, Lips (Hardface); Drag Line Buckets, Runners (Hardface); Drag Line Buckets, Teeth (Hardface); Gravel Screens (Hardface); Hoppers (Hardface); Hopper Lips (Hardface); Power Shovel Teeth (Hardface); Latch Bars (Hardface); Channeling Drills (Hardface); Stone Working Tools (Hardface); Stuffing Box Sleeves (Hardface).

Well Drilling Contractors: Bearings: Arms—Steel (Fab.); Bearings (Rep.); Bearing Struts (Rep.); Casings (Fab. and Rep.); Drill Bits (Rep.); Drill Bits—Weld

BALANCE SHEET

ASSETS		LIABILITIES	
Cash on Hand	________	Accts. Payable	________
Cash in Bank	________	Notes Payable	________
Mdse. Inventory	________		
Accts. Receivable	________		
________	________	Mortgages	________
Furn. & Fixtures	________	Any Other Lia.	________
Trucks	________	TOTAL LIABILITIES	________
Any Other Assets	________	Net Worth	________
TOTAL ASSETS	________	TOTAL LIABILITIES	________

Fig. 9. Balance sheet.

On (Weld.); Gears—Steel (Rep.); Gravel Screens (Rep.); Pump Impeller (Rep.); Reservoirs and Tanks (Fab. and Rep.); Rider Blocks (Hardface); Shafts (Worn) (Rep.); Structural Parts, Towers, Poles, Platforms, etc. (Fab.); Tractor Grouser and Wheel Lugs or Cleats (Fab. and Rep.).

The Application of Hard-Facing Metals: Reclaiming the Scrap Pile; The Business of Keeping Equipment in Running Order; Hard-Facing as a Means of Protecting All Types of Steel Equipment from Wear; Hard-Facing User Benefits; Types of Steel Best Suited for Hard-Facing Applications; Outlining Procedure for S.A.E. Steels; Procedure Outlining High Chrome Alloy Steels; Stainless Steels; High Carbon and Tool Steels; Manganese Steel; Cast Iron; High Speed Steels; Quenching of Deposited Metals; Preparation of Base Metal for Hard-facing; Acetylene Application; Electric Application; Grinding and Hardness; Newspaper Advertisements in Exploiting Hard-Metal and Hard-Facing Metal Shop Facilities.

Structural Welding (Arc Welding for Building Construction): Advantages; How Arc Welding Provides Economy; Other Advantages in Building Construction; Structural Connections; Fabrication Costs; Versatility and Freedom in Design; Connections to Existing Steel; Flexibility to Meet Construction Schedules; Painting and Maintenance; Inspection Fundamentals of Design for Welded Structures; Listing the Fundamentals of Design for Welded Structures.

The Application of Hard-Facing Metals—This section points out how hard-facing metals can be applied to the ordinary equipment found in the vicinity of every commercial welder or job shop. It would be impossible to go into details of every application, but it is hoped that the explanations offered here will enable those who read this work to realize the great importance of hard-surfacing and the savings it will bring to those who use hard metals as well as the profit to the welders who seek out the hard-facing jobs and sell hard metal applications to the owners of the equipment.

Any experienced welder could go into the average scrap pile and find dozens of pieces of equipment that could be saved by building up and made better than new by the application of hard metals. Many welders in rural districts, finding it difficult to make a living, could increase their revenue considerably if they would make a study of hard-facing applications in their own vicinity. It is true that it requires salesmanship to convince the owners of the equipment that a relatively expensive hard metal application would prove to be a sound investment in the long run, but it requires salesmanship to obtain and hold business in any line.

It is not necessary for a good job welder to move to some other locality where business looks better, for if he were to make such a move, he would find competition so keen that he might not be able to pay his moving expenses. The average welder often spends much of his time seeking new locations, or picking up work far beyond the limits of his own district or market instead of digging into the needs for hard-facing in his own community. There are many plow shares, scarifying teeth, power shovel equipment, and other implements in his locality, that could be faced profitably, both to the owner and to the job welder.

This is true not only of the welder who is doing job work for others, but the welder who is employed by others to do the necessary work to keep certain equipment in running condition. The wide-awake welder will always be seeking out new parts to be repaired as well as new applications for hard metals. Such a welder is invaluable to his employers and is always the last one to be laid off when hard times come along.

Hard-facing is the most practical means of protecting all types of steel equipment from wear. It consists of welding a hard, wear-resistant alloy to the point, surface or edge of any part which is subjected to abrasion, by either the electric or the acetylene process. A characteristic of many hard-facing metals is that they attain their maximum hardness and wear-resistance as deposited and require no subsequent heat treatment.

Hard-facing benefits the user in a number of ways. First, it permits the use of inexpensive base metals. Second, it prolongs the life of equipment many times and saves replacements as well as delays. Third, when applied to edged tools it minimizes the number of sharpenings necessary, and in many cases reduces power costs.

Hard-facing is not limited in application to any one type of equipment nor to any one type of abrasion. Hard-facing metals produce equally good results on rotary drilling tools, plow shares, dies, crushing equipment, and innumerable other parts subjected to wear. Because there are different types of abrasion, however, and because other factors such as heat, corrosion and impact are often involved, several types of hard-facing metals are necessary in order to obtain maximum service from every application.

There are certain types of steels ideally suited for hard-facing applications. These steels are easily welded and require no treatment either before or after the hard metal is applied. Many of these steels are well adapted for some types of equipment, while they are entirely unsuited for other types of equipment. As an illustration, S.A.E. 1045, a type of steel which is ideal for hard-surfacing applications, is also well suited for certain types of road making tools, agricultural implements, excavating equipment, etc., but it is not suitable for making shear blades, certain types of dies and other parts which are subjected to severe pressures in use. In such cases, carbon or alloys are added to the steel to insure greater stiffness and strength, and quite often the parts are heat treated. Certain types of alloy steels, high carbon steels, etc. may be successfully hard-faced provided the proper procedure is followed.

1. **Carbon Steels.** (.0-.55): These are the steels which are ideally suited for hard-facing applications. The application may be made to such steels without treatment either before or after welding. This is applicable to either hot or cold rolled steels or steel castings of this carbon range.

2. **S.A.E. Steels:** All of these steels may be hard-faced satisfactorily provided the operator has a knowledge of the condition of the steel. If it is heat treated, the best procedure is to anneal the part prior to hard-facing. If it is in annealed or as-rolled condition, hard-facing may be done without any particular preparation. In the event that the steel is a high carbon alloy, it should be reheated after the hard metal has been deposited (to approximately 1600°F.) and allowed to cool normally in the air.

3. **High Chrome Alloy Steels** (3-12 percent Cr): These steels can be hard-faced successfully, but require great care in handling as they are extremely susceptible to heat in any form. Before hard-facing, proper procedure is to preheat the part to approximately 1200°F.—After the application has been made, cooling should be retarded.

4. **Stainless Steels:** These steels may be hard-faced by either the electric or the oxy-acetylene method—the procedure being much the same as for steels in the medium carbon range. The exception is that less heat is required for hard-facing stainless steels.

5. **High Carbon and Tool Steels:** High carbon steels in the past, so far as hard-facing is concerned, have given welders much trouble. It can now be said, however, that successful applications can be made to carbon steels which run as high as 1.10 per cent carbon and 1.25 per cent manganese. The success of the hard metal application depends entirely upon the treatment given the part after the application. It is, of course, necessary to have the part to be hard-faced in an annealed or as-rolled condi-

tion. After the application, which may be made by either the electric or the oxy-acetylene method, the part should be reheated (without allowing it to cool after welding) to approximately 1600°F. It is then cooled normally in the air. This procedure, while lessening the strength and stiffness of the steel, does not leave it in a condition where failure will be caused by breakage, but rather leaves it in a condition where it will have a tendency to bend or flex. This procedure as outlined also applies to tool steels.

6. Manganese Steel (10 percent-14 percent manganese): Because the grain structure of manganese steel is easily disrupted by the application of heat, it should be hard-surfaced only by exercising extreme care and by carefully following the suggested procedure. Welding should be done only by the electric method. The hard metal should be deposited in small areas as far removed from one another as possible until the entire surface has been covered. This procedure will prevent concentration of heat upon any one part. Manganese steel may be hard-faced with practically any type of hard metal, but it is advisable to apply a layer of stainless steel first as a binding agent.

7. Cast Iron: This metal is not suitable for hard-facing. Where hard-facing is to be done, it is advisable to make the part of either mild or cast steel.

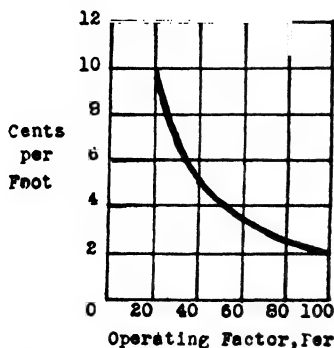
8. High Speed Steels: The hard-facing of these steels is not generally recommended. In cases where it becomes absolutely necessary to surface this type of alloy, the best procedure is to have the part in the annealed state prior to the application and to reheat and cool it slowly after the application is completed.

Size, Inches	CLASSES I	CLASSES II
1/8	1.56 LB/HR	1.56 LB/HR
5/32	2.19 " "	2.50 " "
3/16	3.12 " "	3.75 " "
1/4	4.75 " "	5.10 " "
5/16		7.30 " "

Fig. 10. (left). Chart of welding costs. Fig. 11. (right). Table of electrode deposition rate.

Quenching of Deposited Metals: The heat treatment of any hard metal is not recommended when that treatment requires the use of a quench. Occasionally quenching is considered necessary in order to give the part the strength and stiffness it requires in service. That stiffness, however, is best acquired by a normal or slightly accelerated air cooling.

Preparation of Base Metal for Hard-Facing: It is always advisable to clean the base metal thoroughly prior to hard-facing either by grinding or by buffing to remove all scale or oxides. In cases where the equipment is heavy or where a finished surface is desired it is advisable to preheat the part to a cherry red prior to hard-facing.

Acetylene Application: The composition of many hard-facing metals is such that the atmosphere created by a certain amount of acetylene in the torch flame will produce a quiet, free flowing alloy. If, however, the flame is used on a metal of different analysis it will produce a sluggish alloy with a tendency toward boiling while in a molten condition. Each type of alloy, therefore, requires a different type of flame in order for it to attain the desired physical properties when deposited and in order to facilitate the application.

Electric Application—Many hard-facing metals, either coated or bare, with few exceptions, are applied with reversed polarity. The flux coating on the hard metals facilitates their application, minimizes spatter loss, assures good penetration, helps to stabilize the arc and to prevent oxidation. These coatings, however, should not be allowed to become damp nor should they be exposed to the weather for long periods of time, and it is therefore advisable to store them in a cool, dry place. Bare rods for electric application are generally used only when it is necessary to apply a heavy bead or when it is necessary to weld against a copper form. A general rule to remember in applying any hard-facing metal electrically is to adjust the machine to the highest possible open circuit voltage. On most types of work best results will be obtained if the arc length is as long as possible. The selection of the rod size depends upon the amperage used, which is in turn dependent upon the thickness of the parent metal.

Grinding: Wherever possible, the grinding of hard-facing metal deposits should be avoided, or at least kept to a minimum, as it will be remembered that hard-facing metals are designed for resistance to abrasion, of which grinding is only another form. For that reason it is to be expected that any hard-facing metal will be relatively difficult to grind regardless of the type of wheel used.

Hardness: The property of hardness represents one of the most important characteristics of hard-facing metals. It is so important, in fact, that the hardness of the metals is checked not one or twice a day, but continuously. Obviously, if hardness is so important, then the manner or method by which it is determined is of similar importance.

So many factors enter into the accurate determination of hardness that, at best, results are but comparative. When it is considered that the tensile strength, the elasticity and the compressibility of a metal all exert an influence upon its hardness, it becomes increasingly more difficult to determine which of all the methods of determination is best suited for any specific problem. After careful study and many tests, many manufacturers of hard-facing metal deposits and welders have standardized upon the Rockwell instrument, C scale for determining hardness. This method of determination has proved best, because it has given constantly correct results over a period of years. This applies only to hard-facing metals, that is, those metals which show readings of from 40 to 70 Rockwell C.—Tests made by other methods of determination do not give consistent results, because the accuracy of these readings, at least so far as hard-facing metals are concerned, depends upon the size and thickness of the deposit as well as the thickness of the parent metal.

Newspaper Advertisements: Following are typical samples of newspaper writeups and advertisements intended to assist the job welder in advertising his hard-metal and hard-facing metal shop facilities. In most localities the advertisement headed: "Have your plowshares hard-faced now and save $1.00 per set" should be inserted around the first of January.

The advertisement headed "Only a few days left to save money" should be used between February 15 and March 15. The remainder of the advertisements may be used either before or during the plowing season.

Ad No. 1 Headed: "HAVE YOUR PLOW SHARES HARD-FACED NOW AND SAVE $1.00 ON EACH SET".

Reading: You can avoid possible delay and save money as well by having your plow shares processed during the winter season. Bring in your shares any time between now and March 15. We will process them and allow you $1.00 off per set. Act now.

Concluding: Job Shop Imprint.

Ad No. 2 Headed: "ONLY A FEW DAYS LEFT TO SAVE MONEY".

Reading: After March 15 we will charge full price for processing plow shares so you have only a few days left to take advantage of our special offer. Bring in your shares now and save $1.00 per set!

Concluding: Job Shop Imprint.

Ad No. 3 Headed: "OUR PROCESS SAVES YOU MONEY ON THESE FARM TOOLS".

Reading: Our method of hard-facing keeps farm tools sharp—maintains the suction—and makes them wear three to five times longer than ordinary tools.

You can save money by having any of the following equipment processed in our shop:

Plow shares, field cultivator shovels, spring teeth, rasp cylinder bars, sub-soilers, middle buster shares, drill disks and many others.

Concluding: Job Shop Imprint.

Know Your Costs—The writer recently had an experience which bears out some of the statements made in previous chapters. While visiting a large job welding shop a contractor brought in some power shovel teeth to be rebuilt. He asked the shop owner if he was familiar with hard-surfacing and rebuilding this type of equipment. The shop owner stated that he could do the work and quoted a price which was accepted by the customer. After the customer had left the shop the writer asked the shop owner how he intended to rebuild these teeth, what hard-surfacing material he intended to use and also how he had arrived at the figure which he had quoted.

The answers to all these questions were somewhat vague and the writer therefore proceeded to analyze the job and to suggest the proper procedure. The shop owner was sure that the teeth were carbon steel but the writer very quickly got him out of the notion by trying a magnet on them. The teeth being non-magnetic showed that they were made of manganese, as this is the only non-magnetic metal that the writer knew of which is used on this type of equipment. The writer then tried to ascertain what type of bucket the teeth were to be used on. The shop owner did not know. When asked what type of material was being handled by the teeth he was again forced to admit he didn't know. When the question was asked as to what type of material was to be used for hard-surfacing the writer found that he intended to use a material which, first of all, was not suitable for application to manganese steel; second, was too brittle for use on a shovel tooth; and third, was too high in price.

By this time the shop owner was beginning to see the light of day. He stated that he would built the teeth according to my suggestions if I would consent to talk to the customer over the 'phone and get the necessary information. He said he wanted to do the job right even if he lost money on it because the customer was a good one and he wished to retain his business.

During the conversation with the contractor the writer found that

SINGLE V BUTT GROOVE

Area = $t\,(w + t \tan 1/2\,\phi)$

Weight of deposition per foot = $0.284 \times 12t\,(w + t \tan 1/2\,\phi)$
= $3.4t\,(w + t \tan 1/2\,\phi)$

Deposition Rate - (R)	Volts Required - (V)
Deposition Efficiency - (E)	Amperes Required - (A)
Stub Efficiency - (S)	Power Cost per K.W.H. -(P)
Overall Efficiency - (O)	Electrode Cost per lb.- (C)
Operation Factor - (F)	Labor Cost per Hour - (L)

Speed of Welding per foot per hour - $\dfrac{(R)(F)}{3.4t\,(w + t \tan 1/2\,\phi)}$

Weight of Electrodes used per foot - $\dfrac{3.4t\,(w + t \tan 1/2\,\phi)}{O}$
Note: O = (E)(S)

Power used per foot = $\dfrac{(R)(F)}{3.4t\,(w + t \tan 1/2\,\phi)} \div \dfrac{(V)(A)}{1000} = \dfrac{3.4t\,(w + t \tan 1/2\,\phi)(V)(A)}{1000\,(R)(F)}$

1. Labor cost per foot = $\dfrac{(L)\,3.4t\,(w + t \tan 1/2\,\phi)}{(R)(F)}$

2. Power cost per foot = $\dfrac{3.4t\,(w + t \tan 1/2\,\phi)\,(P)(V)(A)}{1000\,(R)(F)}$

3. Electrode cost per foot = $\dfrac{(C)\,3.4t\,(w + t \tan 1/2\,\phi)}{O}$

TOTAL COST per FOOT = $\dfrac{(L)\,3.4t\,(w + t \tan 1/2\phi)}{(R)(F)} + \dfrac{3.4t\,(w + t \tan 1/2\,\phi)(P)(V)(A)}{1000\,(R)(F)} + \dfrac{(C)\,3.4t\,(w + t \tan 1/2\,\phi)}{O}$

TOTAL COST per FOOT = $3.4t\,(w + t \tan 1/2\,\phi)\left[\dfrac{L}{(R)(F)} + \dfrac{(P)(V)(A)}{1000\,(R)(F)} + \dfrac{(C)}{(O)}\right]$

Fig. 12. Illustration of formula in terms of symbols.

the shovel was the usual type used for general excavating purposes; that is, the regular dipper type—not a drag line or clam shell. The material to be excavated was the usual conglomerate encountered in road building containing very little rock. With this information the writer felt that he was in position to get on to the welding procedure.

Since the teeth were worn down about one inch, the shop owner built them to the necessary length with a coated manganese electrode. Care was taken to peen each layer as deposited and worked on the entire set of six teeth alternately; that is, first a bead was deposited on one side of each of the six teeth and then turned over and the operation repeated on the opposite side. This procedure was carried out very carefully in order to dissipate the heat as much as possible. Then the end and one inch on each side was surfaced with a coated self-hardening rod applied for a distance of one inch

back. This was not a very large job and the original figure that the shop owner had quoted the customer therefore, covered the job very well as far as the materials were concerned. He was considerably out on his labor cost, however, but he was frank enough to explain and admit to the writer that the lesson he had learned more than covered the loss.

The writer has always tried to impress upon his customers certain basic fundamentals regarding hard-surfacing. First of all, one must know the kind of metal which is to be welded. Second, it is important to know what kind of use or abuse to which the part is to be subjected. Third, a fair price commensurate with welding and material costs must be charged and a charge must be added for the experience and knowledge of the shop owner. Fourth, quality is never an accident, but is always the result of high intention, sincere effort, intelligent direction and skillful execution.

An Accurate Cost System Is Important to the Job Welding Shop—Management today is placing more and more importance on cost control. This applies to the oxy-acetylene welding department as well as the arc welding department. If you know your true costs, it will help you to translate what might be thought of as the "expenses" of the work you do into terms of "money savings" for your employers. This will create a greater realization of the importance of your work and get your work for your department in "competition" with other fabricating methods.

Factors Entering Into Costs of Each Job—Basic principles of accounting indicate that costs of operating a welding business can best be broken down into three main classifications—(A) Labor, (B) Materials and (C) Overhead. Items (A) and (B) are the direct costs of labor and materials on each job. Item (C) is an hourly rate to provide for the general expenses of operating the business. This must be added to the direct costs of each job according to the number of working hours spent on it.

(A) LABOR—including time of setting up, preparation, preheating, grinding or chipping, and actual time working with the welding or cutting torch. Helper's time should also be included. Labor charges should be reduced to an hourly rate for each, based on his wages. The number of hours a man spends on a job should be entered on a job record card—along with the rate of his pay. These two figures give one the cost of his work on that job, and, by adding the labor costs of all men who worked on the job, the total labor cost is arrived at.

(B) MATERIALS—(Gases) actual cost of oxygen and acetylene, (dissolved or generated) consumed, in welding, cutting or preheating, including delivery costs. In some cases a small additional charge per cubic foot is necessary to cover possible demurrage charges. If the job is in the production or construction of an item, rather than repair, the cost of sheet metal, plate, pipe and other such material should be added here.

Each welding or cutting torch uses a certain volume of gas per hour. This volume can be determined or established from the manufacturer or from tests of your own. Simply multiply the hours of use by the rate per hour of the torch in question and you have the volume of gas consumed on that job. In welding, approximately equal volumes of oxygen and acetylene will be used, so that, only, needs to be figured. Since the cost, that is the unit cost is known for both oxygen and acetylene (which must include cost of delivery and demurrage on cylinders, if any), it becomes a simple matter to determine the gas costs on any job.

If the acetylene is produced in a generator, costs per cubic foot can

be figured on the basis of a $4\frac{1}{2}$ cubic foot of acetylene yield per pound of carbide. Some shops figure not only generator maintenance into the cost of generated acetylene, but also add in their generator depreciation rather than figure it into the overhead.

(C) OVERHEAD—includes the following:

1. Rent—heat and office expense and/or building maintenance and real estate taxes if these items are available for allocation of costs.
2. Miscellaneous Shop Expenses—fluxes, charcoal, grinding wheels, carbon rods, and, on ordinary repair jobs, pipe and pipe fittings, or steel. On large jobs these items sometimes can be measured easily enough to be charged directly to the job. However, on run-of-the-shop work it is often impractical to try to figure out the cost of such items as one or two welding rods, a little charcoal, or a fraction of a grinding wheel, so that all these minor expenses can well be lumped together under "Overhead".
3. Insurance—covering the shop and equipment, also Workmen's Compensation and any other insurance carried.
4. Taxes—such as social security and other taxes incidental to doing business.
5. Power—electricity for operating lights, grinding wheels, and other such equipment.
6. Depreciation—a most important item. Each time a job is completed, part of the life of the equipment involved has been "used up". This item should include all equipment in the shop which has to be replaced, such as welding and cutting torches, tips, regulators, machines, jigs, and other tools and fixtures.
7. Pickup and Delivery Costs—transportation, trucking, specifically chargeable to department.

Overhead usually can be handled best by reducing it to a "unit" cost per hour. To do this, a careful record of all expenses listed should be kept for a test period of any one typical month, or better still, a whole year. This total amount thus obtained should be divided by the total working hours in the test period (a month or a year) and the result will be the hourly overhead factor. This cost factor can then be added to the labor item. For each hour of labor charged against a job, the hourly overhead factor should be added in also. It is well to check this overhead cost unit regularly, as business conditions change.

If these things are done, a true record of the job cost will result. Operating under such a system, with a reasonable volume of work, any welding department is bound to make money.

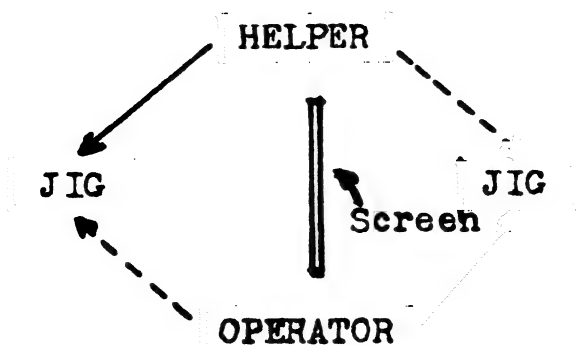



Fig. 13. Efficient set-up.

Some jobs require so little time and such a slight consumption of materials that a cost record is impossible to keep. Yet the mere taking, handling and returning of a job—no matter how small—costs more money in overhead than usually should not be overlooked. For this reason, many shops set up a minimum charge—the amount depending on local plant conditions.

References to the job record cards of past work frequently will produce cost figures on some similar job which will make cost estimating both easy and accurate.

Large shops sometimes set up a cross-reference card system. They have a separate card for each class of work, and as jobs are completed they enter the job numbers on the proper cards. In this way they have an accumulating record of all jobs done in any one classification, without disturbing the numerical order of the job record cards in the main file.

Some shops make a rough sketch of every job on the back of each job record card and add pertinent data, such as the size of the article made or repaired, the extent of the welding and cutting performed, or any unforseen difficulties that had to be overcome. Other shops take a snapshot of each job and file it with the job record card for future reference. The writer has taken snapshots progressively as a large job was being handled. These snapshots are then mounted up in a suitable scrapbook and properly captioned as historical data and also serves to impress a likely prospect on the up-to-dateness and progressiveness and interest displayed in large welding and/or cutting operations.

Establishing Costs for Electric Arc Welding—In electric arc welding the costs comprise the cost of labor, electrodes and power.

LABOR—the cost due to labor depends upon how many pounds of effective metal are deposited per hour—or, in other words, how many minutes per hour the arc is in operation. This time expressed in percentage is known as the operating factor. Obviously, this operating factor is in turn affected by positioning devices, jigs, fixtures and other means of maintaining actual weld production.

As an example, assume a labor rate of $1.00 per hour and an arc speed of 50 feet per hour. Arc speed is the actual rate of travel of the arc and may be expressed in inches per minute or feet per hour. For different operating factors the following costs result. This relation is shown in the curve of Fig. 10.

Operating Factor %	Production Per Hour (Ft. per Hour)	Cost Per Foot
20	10	$0.10
40	20	0.05
60	30	0.0333
80	40	0.025
100	50	0.02

Inspection of the curve in Fig. 10 reveals that the greatest cost reduction can be made by maintaining maximum operating factor.

The weight of deposition per foot is calculated by multiplying the cross-section area of 1a-inches and the weight of steel per cubic inch—0.284 pounds —Deposition rate is the amount of electrode deposited in cubic inches per minute of arc time.

Deposition Rate—is determined in the following manner for the particular electrode to be used. The weight of the electrodes used minus the weight

of stubs gives the weight of electrodes actually used or consumed. The weight of the deposited metal is then subtracted from the weight of electrodes to give the spatter loss, which consists of flux, core and stub losses. It will be noted by observation and record that reverse polarity electrodes have greater spatter loss than straight polarity electrodes. Thus, the percentage of spatter loss is then determined. The rate of deposition per second will be the weight of metal deposited divided by the total welding time in seconds. Then the rate of deposition per second could be converted to the rate per hour by multiplying the results by 3,600.

Fig. 11 offers a table which has been compiled for the rate of deposition in pounds per hour of different grades and sizes of electrodes, organic and mineral, identified by A.S.T.M. and A.W.S. specifications. In Class I (the all-position electrodes) the rate of deposition in flat, vertical, horizontal and overhead positions will be approximately equal; the flat welding positions maintaining the slightly higher deposits, due to less spatter losses. Class II electrodes are used in only flat, downhand, and horizontal fillets.

Deposition Efficiency—Finally, the deposition efficiency is found by the ratio of the deposited weight of metal to the weight of electrodes consumed. The minimum average deposition efficiencies of electrodes, sizes 1/8-inch to 5/16-inch, is 55 to 65 per cent, identified by the foregoing specifications. If a closer check on cost is desired, tests may be made with the electrode specified for a particular job to obtain the ratio of the deposited weight to the weight of the electrodes consumed. The difference will be very small and, therefore, have little effect on the total cost. Another way of securing the deposition efficiency is by subtracting the percentage of spatter loss from 100 per cent.

From the following data on deposition rate, the stub efficiency is ascertained. The stub shall be 2-inches average length from every 14- and 18-inch electrode. The stub efficiency factor shall be 85.7 and 88.9 percent, respectively. Then the over-all efficiency is found by multiplying the deposition efficiency by the stub efficiency.

Operation Factor—The operation factor affects the speed of welding, labor cost and power cost. The operation factor is the ratio of actual arc time to the total pay time. The operation factor has a wide range, from 25 to 35 per cent or greater, depending upon the design of structure and working conditions. In production welding, this factor is probably considered higher. In determining labor cost one must consider every person involved in the completion of the welded joint—the welder, his helper, foreman, engineer—and the job welder's general overhead cost. All these items will tend to bring the labor cost per hour very high. The speed of welding will vary according to the size of electrode and the position of welding.

Power Cost—Usually the speed of welding will be greater in shop welding than in field welding due to the fact that shop welding is generally performed downhand or in the flat position, while field welding may combine flat, vertical and overhead positions. Also the size of electrode used in the field is generally smaller because it is easier to handle. Therefore, the cost of shop welding will be less than field welding. Regarding power cost, it is known that welding motor-generators are more stable than the gas engine generator sets. The former is used mostly in shop welding while the latter is used in field welding.

The cost of power per kilowatt hour (P) multiplied by the weight of deposition per foot, times (V) volts, times amperes (A), and then divided by the deposition rate (R) 1000 and the operation factor (F) will determine

the total cost of power per foot of weld, simplified by the following formula:

Power Cost Per Foot—

$$\frac{(P) \times (V) \times (A) \text{ (weight of deposition per ft.)}}{(R)\ 1000\ (F)}$$

= the total cost of power per foot of weld.

One must consider the consumed power while the electrode is not in operation in order to turn over the generator in an idling stage. This consumption of power varies from 1/4 to 3/8 of the actual arc power used. In transformer equipment this condition does not exist.

The cost of electrodes per foot is determined by the weight of deposited metal per foot multiplied by the cost of electrodes per pound divided by the over-all efficiency. This cost of electrodes will vary with every job, usually depending on the size of the electrode to be used and the position of welding.

Summary—Combining the factors just discussed, the job welder can now develop a common cost formula for the individual groove in any welding position. The thickness of plate and the opening of the groove may vary, but this variation does not effect either the cross-section area or the total cost formulas. The values have only to be substituted into the common equations. In Fig. 12 the formulas are illustrated in terms of symbols. Thus, the cross-section area, of the weight deposited per foot and the total cost per foot, may be determined.

Estimating Welding Designs for Arc Welding—Risking repetition the writer is offering a few straightforward suggestions in estimating any welding design. The following factors have to be considered: volume of welding, deposition rate, deposition efficiency, stub efficiency, over-all efficiency, cost of power per kilowatt hour, electrode cost per foot, labor cost per foot, volts and amperes, and operation factor. Summarizing these, there are just three main factors, namely, labor cost per foot, power cost per foot, and electrode cost per foot, which will be combined in one common formula.

Estimators and draftsmen in industrial plants, shipbuilding, etc. should develop a greater knowledge of welding cost in order to have a more accurate cost figure when submitting bids for a particular job; the reason for this will become more obvious as competition increases.

In standard type grooves, the use of standard formulas is established for the cross-section area of the welded groove. The opening of groove and the thickness of any plate now may be applied to these formulas to determine the cross-section area of weld metal for a given groove. The reinforcement of the weld and the penetration in the backing strip and sidewalls of the groove must be given some consideration in respect to the volume of deposit of weld metal.

A definite welding procedure should be set up or established for a particular job. Then the following factors have to be considered in order to compute a more accurate total cost of weld metal per foot.

Jigs and Fixtures—One method of keeping the operating factor high is by use of the proper jigs and fixtures, and by proper set up. As an example of this, assume it takes a welder two minutes to weld a job and two minutes or slightly less, to set it up. That is a total of four minutes per part, or a total production rate of fifteen per hour. The use of jigs and fixtures is illustrated by providing a helper and another jig. The helper then can set up while the welder is welding and the production is increased to thirty

units per hour, reducing the costs materially. A production of fifteen parts per hour requires a jig, a welding machine and a welder, whereas thirty per hour requires two jigs, a welding machine, one helper and a welder. Cost reduction is obvious because the second fifteen parts are produced at the cost of one jig and one helper, (See Fig. 13).

Another factor affecting the operating factor is the matter of working position. The work should be positioned so that it is easy and convenient for the welder to weld. For example, suppose the operator can always weld in the down-hand position. The speed will then be, say, 26 feet per hour. If, however, it is necessary to weld it in the fillet position, the speed may be only 11 feet per hour, (actual arc speeds).

Reduction of labor cost can be accomplished by obtaining a high operating factor and by the use of proper jigs and fixtures, obtaining proper positioning so as to make it possible to obtain high speeds. These factors are particularly controllable in welded fabrication.

Keeping Cost or Cost Records—It is one thing to "know your costs" but it will avail itself of no use if proper records are not maintained. Whereas general accounting shows merely the total profit or loss of the business as a whole, cost accounting discloses the profit or loss on each unit, whether job, special order, product, class of product, operation or process. It is this accounting for units that distinguishes cost from general accounting.

Before costs can be properly recorded and intelligently controlled, the right basis of costs must be established. More cost systems fail because wrong bases of cost have been established than for any other reason, because they lead to incorrect costs.

PURCHASE REQUISITION NUMBER______ DATE________

To the Purchasing Agent: The following material is required:

NOTE: Each requisition should contain materials which are likely to come from one source only.

QUANTITY	DESCRIPTION	TO BE USED FOR:	JOB NO.

When Needed: To be Delivered at:

Foreman's Approval:

________________ SIGNED:________________

Fig. 14. Purchase requisition.

PURCHASING AND RECEIVING

Purchasing—Not enough attention is usually paid this important phase of a job welding business. Many concerns place their orders for material verbally and fail to confirm in writing, others fail to institute a proper and complete purchase order system. In order to assure that a proper and complete record is made of every transaction effecting purchases it is necessary that the following forms be used in accounting (covering purchases and receipts), all of which are adaptable to the commercial welder or job shop; in accounting for materials in cost records.

1. Request for purchases (purchase requisition) Fig. 14.
2. Purchase order (on the vendor) Fig. 15.
3. Record of receipt of material (receipt voucher).
4. Purchase record (or register used as a history of the past and acts as a guide in current buying).

The "purchase requisition," or "field requisition," as it is often termed, originates with the welding foreman. It is usually prepared in duplicate, original to the office manager or other employee designated to do the buying and the duplicate remains in possession of the foreman as a checkup or followup on purchasing. This form, (See Fig. 14), is believed to be self-explanatory.—The "purchase order" should be prepared from the "purchase requisition" in five copies, the original is mailed to the vendor, the duplicate is retained by the purchasing agent, the triplicate is passed along

PURCHASE ORDER NO. 285

YOUR WELDING COMPANY

DATE: ________

PRICES F.O.B.________ TERMS______ REQ. BY____ APP'D____

SHIP OR DELIVER________ VIA________ CONSIGN TO US AT________

KINDLY ENTER OUR ORDER for the items described below, at prices noted, per instructions hereinabove set forth:

ACCT. No.	ITEM No.	QUAN. REQ'D.	DESCRIPTION	UNIT PRICE	AMOUNT
No	te; T	his wr	iting space to be 4½	inches	in depth

Kindly acknowledge receipt hereof, confirming DELIVERY DATE, prices, terms and conditions hereof.

YOUR WELDING COMPANY

By________

Purchasing Agent

Fig. 15. Purchase order.

to the accounting section for later matching up with approved invoices before placing invoices in line for payment, the quadruplicate copy is given to the storekeeper in order that he may be acquainted in advance of the material ordered and to provide checking facilities and the quintuplicate copy is given to the welding foreman or person originating the "request for purchase" in order that he may have definite knowledge that the material has been ordered and the source of supply. This form, (See Fig. 15), is also believed to be self explanatory.

The chief record used in the receiving or stock room is the "receipt voucher" which should be issued in duplicate—one copy sent to the office and the copy retained in the stock room where it is filed after posting the receiving information to the stock ledger record.

Merchandise sold from stock should be listed on a "sales ticket" in triplicate, the original delivered to the customer, the duplicate turned into the office for entry in the journal as detailed under "office management". The triplicate is retained in the stock room where it is filed after posting the shipping or delivery information to the stock ledger card.

Where much of the work is handled by more than one man, it is well to originate an "order for work", (See Fig. 16). On this form which is issued in duplicate is inserted the shop order number. The "order for work" is issued to the welder by name and it is dated. A description of the work to be handled is incorporated in the body. It is usually prepared on a register, however it may be padded, and the order for work is signed by the welding foreman. The original is given to the welder and the copy remains in the register to be used at a later date for statistical information and record keeping insofar as maintaining cost data is concerned on individual jobs.

The materials used, description or work, traveling time and other expense is noted on the "shop order", (See Fig 17), and on the reverse side is indicated the time report of each welder having anything to do with the particular job, (See Fig. 18). This time is then summarized and a recap is offered directly below on Fig. 18 to include total shop time, travel time, expense, material, and total amount to be billed.

The "order for work" (original copy) is then filed by Job No. and destroyed after one year. The customer's invoice is constructed from the "shop order" and posted directly to the "accounts receivable ledger". The "shop order" is filed by customer name and retained along with the invoice (posting copy). However, if so desired and as a cross-reference, the invoices may be filed separately by invoice number in numerical order and the shop orders may be filed by customers' names in a separate shop order binder by months.

Accounting for Labor—Accounting for labor in the shop, payroll, office and in connection with overhead charges or costs, should have the following objectives:

1. To determine wages due each worker in order that payrolls can be prepared, and so that no worker will be paid more than he has earned. (Refer section captioned "Office Management, Compensation Records")
2. To determine labor costs by units, operations, etc. so that proper direct-labor costs can be entered on cost sheets.
3. To obtain data for calculating overhead expenses.
4. To procure information for proper control of labor costs.

The "time card" is the essential form used to reach the foregoing objectives. Time cards vary according to the kind of labor information desired and the wage system in use, particularly the latter. There are two chief kinds of time cards—one for direct or productive work and another for indirect or non-productive work. The first indicates the labor chargeable to a production order or job ticket, the second the labor that is chargeable to a standing order. It is recommended that the stock room clerk or welding foreman in a small job shop prepare the time cards of the welders. It is further recommended that one time card be prepared daily. All time cards should be forwarded to the office and there used in drawing up payrolls.

Fig. 19 illustrates what is generally called a circular percentage chart, showing profit and loss statement in percentage of net sales in graphic or chart form. The smaller circles at the lower left- and right-hand corners shows the "break-down" of the analysis of miscellaneous expense and the analysis of occupancy expense, respectively.

Fig. 20 illustrates what is generally called a circular percentage chart, showing the expense dollar of a welding concern for the year 1941, indicating the percentage of each dollar expended in the operation of the business to the total.

The items of labor and proportioned charges representing 32.5% and 20% of the total expense respectively, have been broken down by divisions to make up the total percentage.

Many other phases of a commercial welder of job shop business may be illustrated with the use of circular percentage charts to advantage. Comparisons with previous years may be indicated through the use of dotted or broken lines following the division of the caption listed and in this manner it will be readily noted as to what particular expense items indicates an increase or decrease in the current years as compared with the previous year.

Office Management—Every phase of the business heads up in the office, so it is to the responsibilities of office management that this section is devoted. Included is a simple yet complete system of bookkeeping.

Management is the brains of business. Office records are the nerve center. Wherever and however management succeeds or falters or fails, the facts will show up in the records. If the accounting and sales control systems are thorough, the circumstances around those facts will likewise be registered. The more compact, complete, and revealing are these records, the stronger will be management's control over the business. A simple, all-inclusive system will aid the executive in coördinating the functions of the various departments, from office to mechanical maintenance, making for efficiency and economy in the conduct of the job welding shop business.

An inadequate system of accounting and sales control will be readily reflected on the profit side of the ledger, in management discord and in a continually wavering sales volume. All of this comes under the heading of Office Management, for every detail of the business heads up in the office. System or non-system flows from office management.

YOUR WELDING COMPANY

ORDER FOR WORK

SHOP ORDER NO.________ DATE ___________

TO: ________________________________

Description of Work to be Done

____

____

____

____

________________________________Foreman

Fig. 16. Order for work.

So it is the purpose of this section to place at the finger tips of management a simple yet thorough system of accounting and sales control. The accounting system will be illustrated where practical. In addition, another form for keeping payroll records, with provisions for wages and hours, is illustrated and described. The system as described will enable management to locate at a glance his weak spots and get in behind them promptly. This system, if followed through, will enable follow-through to be launched many weeks in advance of the time permitted by cumbersome systems of control. In addition, this section places in the hand of Office Management certain facts and information of value as reference material. This includes a contract form for employees, which is based wholly on legal application. This form will be found practical in many shops. Then, too, the application of the federal wage and hour law to the job welder, is enumerated for ready reference so that it is of invaluable assistance to management. Constant reference to this information will lift some of the load off management. Practical application of certain data will not only enable office management to save a lot of headaches, but will promote efficiency and economy. If the business now employs an obsolete or inadequate system of accounting, a study of the accounting method in this section might be precisely what is needed.

Discussion of the Balance Sheet—In years gone by the problems of accountancy were very simple compared with the problems of today. There were no large manufacturing establishments where the accounting procedure called for depreciation on a vast number of different types of assets, or where the production process involved long periods of time and expenses had to be cut off at a fixed date and where assets were spread over large areas. Business was largely private; the business unit was the proprietorship or the firm.

Evolution of Accounting Principles—The first accounting firm was organized in the United States in 1883 and accountancy was concerned more particularly "with straightening out mixed-up books". Not until the turn of the century did the field of accountancy gradually become more and more concerned with adequate, reliable records. In this process, standards gradually became more and more desirable. The same accounting problem often would be handled in a different manner by different accountants, a policy which was and still is not particularly helpful to investors, creditors, or business analysts. Accountancy is still going through the stage of arriving at a uniformity or standardization. One accounting firm will charge a write-down in inventories to surplus, and another will make the charge to net earnings. One accounting firm will set up the cash surrender value of life insurance asset in the balance sheet and another will set it up as a deferred asset. One accounting firm will set up the current yearly installment of a funded debt as a current liability, and another will allow it to remain as a deferred liability in the balance sheet.

Accountancy, like the medical profession, depends upon individuality. As we have all experienced one doctor will prescribe one method for a cure, while another may have an entirely different approach for the same illness. Many accountants now distinctly advocate the belief that a balance sheet should well nigh speak for itself. The balance sheet should be presented in such a form that it can satisfactorily stand by itself without detailed reference to an accompanying report. Therefore, balance sheets should be more informative than the average present condensed form. An effort should be made on working toward a fully descriptive balance sheet for

YOUR WELDING CO

SHOP ORDER
NO. ______

Ordered By__________ DATE______ | FOR ______________
Received By______ Promised______ | ______________
Approved By______ Date Billed____ | ______________
Contract ______ No. Tickets This Order______ | Terms________ Ship via________

MATERIALS USED			DESCRIPTION OF WORK
Traveling & Other Exp			Delivered to:
TOTAL:			

Fig. 17. Shop order.

all business including the commercial welder or job shop. However, each type of business necessarily has different needs from the standpoint of presenting its financial condition and in many cases the same type of business, because of size, has different problems. While it is not possible to get absolute uniformity in statements for each division of trade, there should not be such a wide variation in the Job Welding Shop, so as to preclude or make impossible uniformity in the preparation of balance sheets.

All balance sheets should be set up so that the computation of such items as current assets, current liabilities, fixed assets, inventories, would be uniform. In the same way profit and loss statements, and surplus accounts, should be so set up that the computation of net profits in all cases would be on the same basis.

What Books to Keep and Why—It is the writer's purpose to design the particular form and arrangements to make the bookkeeping system fit the needs of a commercial welder or job shop.

Books of Original Entry—Every financial transaction can be recorded in the form of a journal entry. Transactions occur on either a cash or a credit basis. According to this twofold classification the journal is subdivided into two parts, one employed to record cash transactions and the other to receive all other transactions. On the basis of this classification it is customary to subdivide the original journal into two separate books, one the "general journal", in which all entries except cash are made, and another known as the "cash journal", in which cash transactions only are entered. The two journals required to record cash receipts and disbursements, respectively, are usually combined in one book, known as the "cash book", the pages for each alternating throughout the book. Cash receipts are

entered on the left-hand page and cash payments on the right-hand page.

Functions of the Cash Book—The cash book takes the place of a detailed cash account in the general ledger, only the total receipts and payments being posted periodically to the cash account in the general ledger.

The Ledger—The ledger is a record in which accounts are kept. There are two general classes of accounts—real and nominal. "Real accounts" record assets, liabilities, and "nominal accounts" record gains, expenses, losses. The account is designed to bring together all items relating to that account, and represents a summarization of this data. Items on one side of the account represent additions. Those on the other side represent subtractions. The difference between the two sides of the account is the balance. If the excess is on the left-hand side of the account, it is a debit balance; if on the right-hand side, it is a credit balance. The ledger accounts taken together form an equation similar to that represented by the balance sheet or financial statement.

Subdivision of Ledgers—A single general ledger suffices only in the case of a small commercial welder or job shop. It soon becomes necessary to segregate certain classes of accounts in subordinate ledgers; the accounts thus treated first are in most instances those with customers "accounts receivable ledgers" and with creditors, "accounts payable ledgers". All other classes of accounts are set up in what is known as the "general ledger". As to rulings, ledgers are standard, and balance. "Standard ruling" has two duplicate parts, debit and credit, division line usually being in the center of the page. "Balance ruling" is a three and four column ledger with money columns either at center or at the right-hand margin, or at both center and right-hand margin. Extra columns are for account balances. If balance is usually either a debit or a credit only one balance column is necessary; but if the balance is apt to change from a debit to a credit, or vice versa, both debit balance and credit balance column should be provided. This form of ruling is particularly useful for personal accounts which require that the balance be kept uptodate.

As to "bindings", ledgers are solid-bound, loose-leaf and card. Loose-leaf and card ledgers possess greater flexibility than do bound books. They may be arranged according to any desired grouping and all dead material is easily discarded or filed away in reserve binders. Removal of leaves or cards makes it possible to subdivide clerical work.

Closing the Books—To balance the accounts is really a very simple matter—it consists merely of footing the debits and credits, finding the amount by which the one side is larger than the other, adding this amount to the smaller side "to balance", and bringing the same amount down on the other side to serve as the new starting point, or balance.

The accounts are now listed as they appear on the ledger, showing the debit balances in one column and the credit balances in another. Such a list or statement of ledger accounts is technically known as a "trial balance". The totals of the debit balances must always be equal to the totals of the credit balances.

Financial Statements—The ultimate objectives of all accounting are the monthly financial reports. Too many reports merely show conditions as of a certain date or what was accomplished for a given period. They do not show what has been done progressively—they do not show the trend. The financial report illustrated in this section indicates the "results" for the current month and the "year to date". This indication of trend makes possible

for management to plan for the future. This is most important to Job Welders because of the seasonal nature of the business in some localities. The reports consist of:

1. The Balance Sheet (in two sections):
   a. Statement of Assets
   b. Statement of Liabilities
2. The Profit and Loss Statement (in three sections):
   a. Summary Profit and Loss Statement
   b. Manufacturing Statement (where fabrication or manufacturing of parts is specialized in—in the Job Welding Shop)
   c. Expense Schedule.

Figs. 21 and 22 illustrate the statement of assets and the statement of liabilities. They are arranged to show, in addition to account balances, any increases or decreases from the previous month.

The "summary profit and loss statement", (See Fig. 23), is arranged to show gross profit on:

a. Apparatus and Supplies Sales
b. Job Shop Work (Repair Jobs)
c. Electric Arc Welder and Other Equipment (Rentals)

TIME REPORT

NAME	DO NOT WRITE IN THIS SPACE	CLOCK
TOTAL SHOP TIME		
TRAVEL TIME		
TRAVEL TIME		
EXPENSE		
EXPENSE		
MATERIAL (From Other Side)		
EXPENSE (From Other Side)		
TOTAL AMOUNT TO BE BILLED		

Fig. 18. Time report.

The figures for (b) and (c) are, of course, taken direct from the general ledger. The cost of apparatus and supplies sales is taken from the "manufacturing statement", (See Fig. 24), net operating profit is obtained by deducting delivery, selling, and administrative expenses from total gross profit. These expenses are detailed on the "expense schedule", (See Fig. 25).

The summary "profit and loss statement", the "manufacturing statement", and the "expense schedule" are arranged with columns to show both current-month and year-to-date figures, and the percentage in both cases.

Compensation Records—Social security and wage-hour legislation requires that a record be maintained for each employee in addition to a record of all wages paid and the deductions for federal old-age annuities. Fig. 26 is a convenient form for compensation records. Inasmuch as it is a requisite, also, that each employee be supplied with a statement of his earnings and payroll deductions, either annually, semi-annually, or at the end of each pay period, a small form of earnings statement headed "pay-roll remittance voucher" is illustrated in Fig. 27. Both Figs. 26 and 27 include full details about the employee and are easily exhibited for inspection when government representatives make scheduled or pop calls. It is also readily accessible to the management and provides prompt information on an employee.

Through following the preceding discussion and illustrations carefully one finds himself in possession of the principles of bookkeeping as may be successfully applied to all commercial welder or job shops. A good rule to observe is "never to make the business fit into a particular bookkeeping system".

Buying for the Office—In general "Don't use the same expensive purchase routines that are required for raw materials, equipment, etc., when buying office supplies, janitor supplies, and other miscellaneous classifications".

It is the job of the local stationery-man to assist with materials and methods in order that the Office Management may operate more efficiently.

It has been said that a business without its papers has lost its memory. Such a viewpoint places proper emphasis upon the value of the service rendered by files. But, much depends upon the "system" used. And equally important to earnings, are the supplies that comprise the "system".

Inadequate indexing, bedraggled guides and folders, cause far more filing errors than unintelligent handling on the part of a file clerk. It follows that if a business suffers from misfiling, from actual loss of papers or documents, the remedy probably lies in improvement of the tools needed. One cannot expect first-class filing service from second-class filing equipment. Files can pay excellent dividends in convenience. Executives and clerks who are served by files, soon react to the results they deliver. Prompt, complete reception of needed material tends to prompt completion of every task assigned. Delays provide ready excuses for slowed-up work. It pays for the commercial welder or job shop to investigate filing conditions thoroughly.

Stationery Requirements for the New Year—The following list should be checked carefully for the routine things that are usually required at the beginning of the year—1. Accounting Forms, 2. Calendars, 3. Daters, 4. Diaries, 5, Filing Supplies, 6. Inventory Supplies, 7. Transfer Cases.

Credits and Collections—Productive results in the credit and collection end of business may largely be attributed to an efficient credit executive, whether it be the manager or his designated credit man in the job welding shop business.

In the earlier period of our economic history, the purely industrial ele-

ments of our economic life were concerned chiefly with the provision of food, clothing and shelter. Business organizations were small then; investments of capital were not great and the supervision of business operations was not difficult. Then, credit granting was largely a matter of personal relationship and credit learning was limited to every man's common sense, improved by easy experience.

But times have changed. Great and rapid changes in world affairs have much to do with the possibilities of business success or business failure. All of this has considerably reduced the margin between unsuccessful and successful business operation and to the extent that this margin has been reduced there has been a corresponding increase in the responsibilities of the credit executive. In the present disturbed state of industrial management a credit executive must possess a host of knowledge.

First among them may be named—correctness and precision in the use of English. This may sound rather elementary but it is not. The credit man who keeps himself informed on good usage and taste in English benefits the business he represents and the credit profession. He who is efficient in credit management must possess the quality of being able to speak and write interestingly, convincingly and briefly. His letters must be direct, discreet, winning and ordinary conversation with customers and business associates must hold attention and gain information.

Secondly, an efficient credit man must have good manners which are the expression of fixed habits of thought and action. Credit departments of any business managed by roaring Simon Legree's have wrought appreciable financial injury to the firm they represent. Goodwill values accumulate with the years and the customer never forgets. And competition is so keen today and merchandise is so standardized and there are so many places where one's wants can be supplied, that the success or failure of a business may rest largely upon a single factor of employee-courtesy.

As a third evidence of efficiency is named the power and habit of reflection. Training and cultivating the mind through the power of habit and reflection will produce ideas of real value to the credit man in his daily

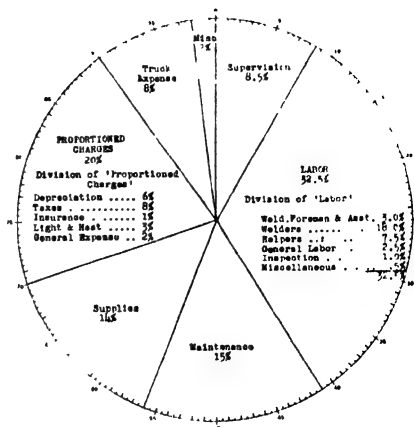
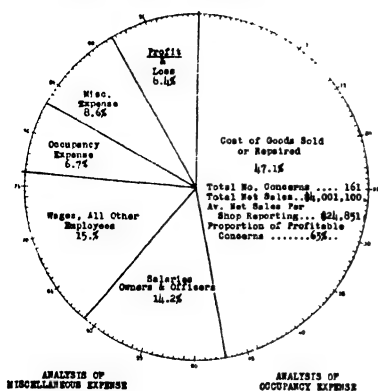



Fig. 19, (left). Circular percentage chart. Fig. 20, (right). Another circular percentage chart.

STATEMENT OF ASSETS

INCREASE OR DECREASE	$	ACCOUNTS	DETAIL	TOTAL
		CURRENT ASSETS		
		Cash and Bank		
		101 - Office Fund		000.00
		105 - Bank		000.00
		Total Cash and Bank		000.00
		Accounts & Notes Receivable		
		111 - Accounts Receivable		000.00
		115 - Notes Receivable		000.00
		116 - Contracts Receivable		000.00
		Total		000.00
		118 - Less Reserve Bad Debts		000.00
		Net Accts.& Notes Rec.		000.00
		Inventories		
		121 - Apparatus		000.00
		122 - Supplies		000.00
		123 - Arc Welding Machines		000.00
		124 - General Supplies		000.00
		125 - Finished Stock		000.00
		Total Inventories		000.00
		Total Current Assets		000.00
		FIXED ASSETS		
		151 - Land		000.00
		152 - Buildings	000.00	
		152R- Less Res.for Deprec.	000.00	
		Net Buildings		000.00
		153 - Office Furn.& Fixtures	000.00	
		153R- Less Res.for Deprec.	000.00	
		Net Off.Furn.& Fix.		000.00
		154 - Machinery & Equipment	000.00	
		154R- Less Res.for Deprec.	000.00	
		Net Machy.& Equipment		000.00
		156 - Delivery Equipment	000.00	
		156R- Less Res.for Deprec.	000.00	
		Net Delivery Equipt.		000.00
		Total Fixed Assets		000.00
		Deferred Charges		
		171 - Unexpired Insurance		000.00
		172 - Prepaid Advertising		000.00
		175 - Prepaid Tire Expense		000.00
		176 - Prepaid Truck Repairs		000.00
		177 - Prepaid Taxes		000.00
		179 - Other Prepaid Expense		000.00
		Total Deferred Charges		000.00
		TOTAL ASSETS		000.00
		Month and Year		

Fig. 21. Statement of assets.

work. He may not always be able to determine the absolute truth, but a few minutes spent thinking about a matter may bring surprising results. Serious mistakes may be avoided, new ways of working to better advantage may be gained, new opportunities for constructive effort may present themselves unexpectedly to the mind.

As a fourth evidence of efficiency may be named "initiative". Initiative is the ability to reason out a course of action and to take that course decisively and energetically. It is one of the basic elements of business success. Without it, no credit man, of all persons, need hope to travel far. It is wise to encourage initiative.

As a fifth evidence of efficiency may be named the power of growth. The power to grow comes from getting away from the narrow limitations of one job. Everyone cannot help experiencing a certain narrowing effect from his daily work. If we do not guard against this the mind trained to a certain point crystallizes, as it were, and refuses to grow. How to get away from "one job"? The answer seems obvious. For every vocation including the job welding shop business there are trade journals, group discussions and meetings of various types which are facilities for growth. For the voca-

tion of credit management there is a trade journal of superior excellence—credit and financial management. In it the credit man will always find patches of fruit-bearing knowledge directly helpful to him. He may be enlightened and broadened by an editorial. Attendance at meetings of his local Association, participation in credit group activities—all enables the credit man to gain knowledge, keenness of mind and breadth of vision. The credit executive who lives only in the narrow world of his own experience will be narrow in his ideals and aims. He will lack the power of growth.

As a sixth and final evidence of efficiency is presented—the right objective. It is not enough for a man to know how to work and to work hard—he must work in the right direction. Misapplied and misdirected energy reduces the power to do. The primary objective of every business is to earn a profit. Everything else is secondary. "Losses" may, and frequently do, damage profits. So the vital objective of the credit man's job is to maintain as nearly as humanly possible a balance between "risk" and the profit-value of a business offered. If this were not so there would be little future for credit executives. It should therefore be the primary object of the credit man to guard profit with every means at his disposal.

STATEMENT OF LIABILITIES

INCREASE OR DECREASE	%	ACCOUNTS	DETAIL	TOTAL
		CURRENT LIABILITIES		
		Notes & Accounts Payable		
		201 - Notes Payable - Bank		000.00
		202 - Notes Payable - Other		000.00
		205 - Accounts Payable		000.00
		Total Notes & Accts.Payable		000.00
		Accrued Liabilities		
		211 - Accrued Pay-Roll		000.00
		212 - Employee Pay-Roll Contributions:		
		212E- State Unemploy.Ins.		000.00
		212F- Federal Unemploy.Ins.		000.00
		212G- Federal Old-Age Annuity		000.00
		Total Accrued Liabilities		000.00
		Total Current Liabilities		000.00
		FIXED LIABILITIES		
		221 - Mortgages Payable		000.00
		Total Liabilities		000.00
		CAPITAL		
		251 - Preferred Stock Auth.	000.00	
		252 - Preferred Stock Unissued	000.00	
		Preferred Stock Issued		000.00
		255 - Common Stock Authorized	000.00	
		256 - Common Stock Unissued	000.00	
		Common Stock Issued		000.00
		261 - Surplus		000.00
		271 - Profit & Loss		000.00
		Total Capital		000.00
		TOTAL LIABILITIES & CAPITAL		000.00
		Month and Year		

Fig. 22. Statement of liabilities.

There is an old, but nevertheless true, saying—that the job is never completed until the account is collected. The credit man must be particularly watchful to keep his accounts paid up and liquidated. Frozen assets prove embarrassing, if not fatal. Recognizing the importance of this situation, a series of collection letters is offered in an effort to "turn the trick" and "keep customers smiling". Three short form letters are offered (Refer A, B and C) together with a form letter suggesting the transfer of an account to other hands for collection. (Refer D). Then follows a 4x6 suggested card "Record of Collection Activity," (See Fig. 28), which ties in with A, B and C or the card may be dispensed with and a summarization made on the file in much the same form, (See Fig. 29).

Letters A, B and C may be printed in the form of notices and enclosed in envelopes (printed on post-card size). Either letter or printed notice form will be found acceptable.

(A) YOUR WELDING COMPANY

(Address to be inserted)

Date

Your account as of the above date reflected overdue balance in accordance with terms as shown on invoices. If you have not already mailed remittance, will you kindly do so upon receipt of this notice.

Thank you.

CREDIT DEPARTMENT.

(B) YOUR WELDING COMPANY

(Address to be inserted)

Date

We have not received at this time, your remittance covering overdue account previously brought to your attention.

Please forward check now if it has not already been mailed. Or, should there be any question regarding accuracy of charges, please advise promptly so that we may make any adjustments if in order.

Your prompt attention will be appreciated.

CREDIT DEPARTMENT.

(C) YOUR WELDING COMPANY

(Address to be inserted)

Date

We are still without remittance covering your overdue account previously brought to your attention.

No doubt you have overlooked the length of time we have granted beyond terms shown on invoices. Your prompt attention is requested which will avoid the necessity of considering a change in terms pending adjustment of your account.

CREDIT DEPARTMENT.

P. S. If remittance has been mailed, kindly disregard the above and accept our thanks.

(D) YOUR WELDING COMPANY

(Address to be inserted)

Date

We have written you several letters (or collection notices) without a reply. During the time that has elapsed since we began following you for payment of this balance, we have received no remittance from you to apply on your past due account.

We regret to advise that unless we receive a remittance to apply on account by ten days from the date of this letter we shall have to arrange to transfer your account to our attorneys for their handling to a swift and satisfactory conclusion.

CREDIT DEPARTMENT.

(D-1)

YOUR WELDING COMPANY
(Address to be inserted)

Date

We are still without remittance as requested in our letter of ...., therefore, we have no alternative other than to transfer this balance to our attorneys.

We regret this step but feel that we have shown you every leniency and courtesy in the handling of this matter.

We should like to point out to you again that you may still avoid this step by mailing check special delivery to us immediately upon receipt of this letter.

CREDIT DEPARTMENT.

NOTE:—A reply to any of the foregoing letters from the customer will necessitate a breaking up of the remainder of the collection series and handling the account on a "personal" basis—that is, a direct reply should be forthcoming based upon customer's contention or promise to pay.

Safety—It takes a hundred years to test out a new idea, or to really understand and know the essence of a difficult problem. That is particularly true when the problem involves the intricacies of human behavior. Take for example, safety!

PROFIT AND LOSS STATEMENT

MONTH			YEAR TO DATE	
Amount	%	ACCOUNTS	%	Amount
000.00		APPARATUS: Sales		000.00
000.00		Cost of Sales		000.00
000.00		Gross Profit		000.00
000.00		SUPPLIES: Sales		000.00
000.00		Cost of Sales		000.00
000.00		Gross Profit		000.00
000.00		REPAIR JOBS: Sales		000.00
000.00		Cost of Sales		000.00
000.00		Gross Profit		000.00
000.00		MISC: Sales		000.00
000.00		Cost of Sales		000.00
000.00		Gross Profit		000.00
000.00		RENTAL: Cylinder Demurrage		000.00
000.00		Equipment		000.00
000.00		TOTAL GROSS PROFIT:		000.00
000.00		Delivery Expense		000.00
000.00		Selling Expense		000.00
000.00		Administrative Expense		000.00
000.00		TOTAL EXPENSES:		000.00
000.00		NET OPERATING PROFIT:		000.00
		OTHER INCOME:		
000.00		901 - Discounts Earned		000.00
000.00		902 - Interest Earned		000.00
000.00		903 - Sale of Scrap		000.00
000.00		909 - Misc.Gains		000.00
000.00		TOTAL OTHER INCOME:		000.00
000.00		TOTAL NET OPERATING PROFIT & OTHER INCOME		000.00
		OTHER CHARGES:		
000.00		951 - Discounts Allowed		000.00
000.00		952 - Interest Cost		000.00
000.00		959 - Misc.Losses		000.00
000.00		TOTAL OTHER CHARGES:		000.00
000.00		NET PROFIT		000.00
		Month Ending		

Fig. 23. Profit and Loss statement.

MANUFACTURING STATEMENT				
MONTH		ACCOUNTS	YEAR TO DATE	
Amount	%		%	Amount
000.00		Mfg.Materials Invty.Begin		000.00
000.00		Purchases		000.00
000.00		TOTAL		000.00
000.00		Mfg.Materials Invty.Ending		000.00
000.00		MATERIALS CONSUMED		000.00
		Manufacturing Expenses:		
000.00		501 - Salaries, Supervision		000.00
000.00		502 - Salaries and Wages		000.00
000.00		504 - Payroll Taxes		000.00
000.00		505 - Workmen's Comp.Ins.		000.00
000.00		506 - Mfgr.Supplies		000.00
000.00		507 - Power		000.00
000.00		508 - Water		000.00
000.00		510 - Heat & Light		000.00
000.00		512 - Laundry		000.00
000.00		514 - Depreciation		000.00
000.00		516 - Insurance		000.00
000.00		518 - Rent		000.00
000.00		519 - Taxes		000.00
000.00		520 - Repairs & Maint.		000.00
000.00		521 - Miscellaneous		000.00
000.00		TOTAL MFGR.EXPENSE:		000.00
000.00		TOTAL COST TO MANUFACTURE (or Fabricate)		000.00
		COST OF GOODS SOLD STATEMENT:		
000.00		Finished Stock Invty.Begin.		000.00
000.00		Cost to Mfgr.as above		000.00
000.00		TOTAL		000.00
000.00		Finished Stock Invty.Ending		000.00
000.00		Cost of Goods Sold:		000.00
		Month Ending		

Fig. 24. Manufacturing statement.

The public, as a rule, does not look beyond the externals. The average employer still thinks of accident prevention in terms of "stunts". Almost any alert safety man can take over an industry, a logging camp, or a canning factory and make remarkable reductions in its accident rates within the first years. If safety work has never received serious consideration, the plant will be in urgent need of physical improvement. The less expensive of these changes will probably receive attention. Some of the more glaring unsafe practices will be corrected.

The familiar parades and drum beatings, the poster displays and the contest pressures can be applied in the effort to control accident losses. These stunts have been tried thousands of times. They have a recognized place in the accident prevention program. But they are not the final answer in making safety really a part of the business.

Take the comparable problem of "quality of goods produced or workmanship performed". Every employer knows that by certain procedures he can interest the workers in improving the quality up to relatively high standards. But the real problem is not merely to raise quality to a temporary

level; it is to maintain and improve still further the standards of excellence to meet the demands of a public that is becoming more and more exacting. The safety man must keep in mind that his biggest task, after all, is to establish new and ever higher standards of safety relationships and attitudes. He must convince both the employer and the worker that Safety is a fundamental part of the operations of the plant, that it is a sound element in management that results in operating economies. He must dispel the notion that accident prevention is merely a nice gesture of philanthropy, commendable but expensive. And he must build up the conviction that any product with the stain of blood upon it cannot be a quality product, nor is the industry that produces it a quality industry.

Better understanding of safety will come to us as the years roll by. But all of us will be helped if we will take time to compare this job of accident prevention with other high endeavors in the struggle for the best that life can give.

Accident Prevention—Accident prevention is not an easy job; it is not a job to be accomplished in one brief period and then to be forgotten. If the desired results in safety are not obtained, the solution is to go back again to the equipment and the processes which may cause accidents, find out what is wrong with them, and take the necessary corrective action.

It is true that some companies are able to achieve a very great reduction in accident rates in a very short period of time.

Such successes are clearly the result of unusual ability, unusual enthusiasm, with a possibly reasonable amount of good luck thrown in.

These are the same reasons which produce unusual successes of other kinds. If a new company enters a particular industry, and in the course of a few months is turning out a better product at a lower cost than companies which have been in the field for many years, the answer is ordinarily to be found in certain definite qualities of management.

Long ago someone said that "safety is like riding a bicycle; if you stop pedaling you fall off". This expresses a fundamental truth. It is just as true, however, that in other ways safety is not at all like riding a bicycle. For example, there is nothing routine about accident prevention. A successful safety program must be varied, and it must incorporate many methods for detecting and correcting unsafe conditions and unsafe practices. But the keynote of it all is persistence. A three months' safety contest will not solve the accident problem for a year. There is nothing wrong with the idea of safety. These employers who fail to make the idea a reality in their businesses simply overlook the fact that the achievement of safety, like the achievement of all other worthwhile things, comes only as a result of tenacity and persistence. We must go at this business of safety as though it were a life-long job—which it is!

Management in the Safety Program—The focal point of industrial safety is the relationship existing between the employee and his foreman. The more safety can be personalized—the more it can be continuously presented to men by their immediate supervisors, the more the frequency and severity rates will drop.

Management's responsibility for protecting the worker cannot be overstated. First, there must be a sincere interest on the part of management.

Second, it is the duty of management to provide safe machines with the latest mechanical safeguards.

Third, there must be good industrial housekeeping—a clean plant with orderly aisles and other floor space and good stock conditions.

MONTH Amount	%	EXPENSE SCHEDULE ACCOUNTS	YEAR TO DATE %	Amount
		DELIVERY EXPENSE:		
000.00		601 - Executive Salaries		000.00
000.00		602 - Driver's Wages		000.00
000.00		603 - Payroll Taxes		000.00
000.00		604 - Workmen's Comp.Ins.		000.00
000.00		605 - Gasoline		000.00
000.00		606 - Oil and Grease		000.00
000.00		607 - Tires		000.00
000.00		608 - Garage Supplies		000.00
000.00		609 - Depreciation		000.00
000.00		610 - Insurance		000.00
000.00		611 - Repairs & Maint.		000.00
000.00		612 - Miscellaneous		000.00
000.00		TOTAL DELIVERY EXPENSE:		000.00
		SELLING EXPENSE:		
000.00		701 - Executive Salaries		000.00
000.00		702 - Salesmen's Salaries		000.00
000.00		703 - Commissions & Bonuse		000.00
000.00		704 - Payroll Taxes		000.00
000.00		705 - Workmen's Comp.Ins.		000.00
000.00		706 - Advertising		000.00
000.00		707 - Automobile Expense		000.00
000.00		708 - Telephone & Telegrap		000.00
000.00		709 - Miscellaneous		000.00
000.00		TOTAL SELLING EXPENSE:		000.00
		ADMINISTRATIVE EXPENSE:		
000.00		801 Executive Salaries		000.00
000.00		802 Office Salaries		000.00
000.00		804 Payroll Taxes		000.00
000.00		805 Workmen's Comp.Ins.		000.00
000.00		806 Stationery & Office Su		000.00
000.00		807 Heat, Light & Water		000.00
000.00		808 Telephone & Telegraph		000.00
000.00		809 Laundry		000.00
000.00		810 Depreciation		000.00
000.00		812 Insurance		000.00
000.00		813 Rent		000.00
000.00		815 Taxes		000.00
000.00		817 Repairs & Maintenance		000.00
000.00		818 Postage		000.00
000.00		819 Accounting & Legal		000.00
000.00		820 Losses on Bad Accounts		000.00
000.00		821 Miscellaneous		000.00
000.00		TOTAL ADMINISTRATIVE EXP.		000.00
000.00		TOTAL EXPENSES Month Ending		000.00

Fig. 25. Expense schedule.

Fourth, foremen should be interested and instructed in safety education so that they might better instruct the men in their charge and see that none but experienced and careful operators are on the job. Foremen should be schooled in small groups to insure this.

Fifth, the subject of safety should be brought forcefully to the attention of the entire organization periodically through the medium of contests, safety exhibits or mass meetings.

Obviously, the fullest realization of these five points can only be attained when it is translated to the men at the job through the foremen. The problem of industrial safety is very much akin to that of highway safety. In the last analysis, the human element is the chief factor and reaching that key element requires continuous alertness on the part of men and management.

SAFETY IDEALS APPLICABLE TO THE JOB WELDING SHOP

Goggle Cleaning Unit—This can be easily made. A hand lotion bottle is mounted on a panel alongside an ordinary tissue paper dispenser. This bottle is filled with one of the popular cleaner solutions.

Safety Railings for Floor Openings—A protective railing may easily be installed at floor openings to reduce the danger of men falling into them. The device consists merely of angle irons welded together. When not in use the frame is either lowered below floor level, resting on angle irons fastened to curbing and the cover put in place or the frame may be removed and set to one side and the cover put in place. The railing or frame is of light material and is easily handled by one man.

Slipping Hazard Reduced on Machine and Welding Tables—There are a number of machine tools with cast iron tables on which operators must stand in the performance of their duties. After long use, the surfaces of the tables wear very smooth, causing a dangerous slipping hazard, especially when the tables are oily. To eliminate this hazard, grooves may be cut 1/8-inch wide, 1/16-inch deep and 1/2-inch apart, both lengthwise and cross-wise of the table. This does not impair the use of the table as a part of the machine, but it does give the operator an improved foothold. The method applies to any metallic surface on which men stand.

The Value of Eye Protection—The inability of a spot welder to realize that his face shield could be used for anything other than protecting his eyes when spot welding, resulted in his losing seven days when a particle of weld entered his eye as he was shaping the weld with a chisel. The operator conscientiously wore his face shield when performing his normal operations as a spot welder, but when he had on one occasion to chip off a piece of weld with a chisel, he did not appreciate the value of the face shield in protecting his eyes from this type of flying particle. This accident is typical of many wherein the operator fails to carry through his protective equipment from the routine job to the occasional or odd job. In this particular case, the supervisor failed to emphasize the value of eye protection on jobs other than the operator's routine job.

Empty Drums (Dangers of Exploding)—Many empty drums continue to store explosive vapors. The most common of explosions in the welding game is the application of a torch in an effort to reclaim the drum for some specially adapted use such as making work-benches. When the torch burns through the drum itself it is apt to explode if it contains any remaining vapors of several varieties of chemicals. All drums should be thoroughly purged before applying heat.

Insist upon standardization and use of all equipment necessary for safe operation, such as goggles, hand shields, safety shoes, and safety clothing. This is an obvious and essential preliminary to any accident prevention program, but to make effective planning of safety it is necessary to train the worker to think safety and work safety, and to train the supervisor that it is his job to help the workman to prevent accidents.

Safety as Practiced in the Job Welding Shop—There are some places in nearly every plant or shop where it is never permissible to do any sort of work which makes flame, heat or sparks. For instance, extreme care is always necessary near explosive gases or flammable liquids; and such things as smoking, welding or cutting torches, electric arc welding, open lights, sparking tools, and every other possible source of ignition must be prohibited.

Knowing the ways that fires may start is an important step in learning how to prevent them. Heat sufficient to start fires may come from the oxy-acetylene flame itself; from the metals being welded or cut; from molten slag and metal that blows or drips from the cut; and from sparks which fly from the work.

Some materials will catch fire from these sources of heat more quickly than others. Flammable gases and liquids, with air or oxygen present, are examples of materials that would flare up at once. Oily waste and rags, and light materials such as burlap, excelsior, cartons, straw and waste paper catch fire less easily but burn vigorously once started.

Wooden flooring, timber structures, scrap lumber, wood chips, tarpaulins, rags, and similar materials are even less apt to catch fire than the others mentioned. Yet this is all the more reason why special precautions must be taken with these combustible materials. For fires started in them may only smolder at first, and then may flare up sometime later—due possibly to a gust of air or a natural draft created by the smoldering heat.

Heat from the metal being welded or cut may sometimes be the cause of fires, if hot pieces of metal are allowed to touch materials that burn easily. This is more apt to happen in the case of cutting steel and iron, because small pieces are often cut away from larger sections and are allowed to drop onto the floor or ground. The smaller or narrower the piece cut away, the more heat it will have absorbed, and the more likely therefore to set fire to burnable materials.

Pieces of iron or steel which may have been heated to a bright red may retain enough heat to start fires for 5 to 15 seconds or even much longer under some conditions. Even though the piece may be at a black heat in daylight, it can scorch such things as wood or paper and a fire may start if there is enough draft.

The molten slag that drips or blows from a cut is generally more apt to set fire to nearby combustible materials than pieces of red hot metal. This is because the slag is at the temperature of molten steel when it falls, and therefore it stays hot longer. However, when the slag drops from a height of about 15 feet or more, it tends to scatter and cool more quickly than would a small piece of red hot steel dropped from the same height.

COMPENSATION RECORD

Name ______ Telephone ______ Employee S.S.Acct.No. ______

Address ______ Male / Female ______ Married / Single ______ No. of Dependants ______ Color ______ Age ______

Exempt From ______ Fed.O.A. / Fed.U.I. ______ State U.I. ______ Reason ______ Date Employed ______ Kind of Work ______

Rate $ ______ Per ______ Full-Time Weekly Hrs. ______ Date Employ't Terminated ______ Reason ______

DATE		Time Worked (Days or Hrs)	EARNINGS	DEDUCTIONS			PAID		REMARKS:
Period Ends	Paid		Salary & Comm.	Old-Age Annuity @ %	F.O.A.B. @ %		Net Amount	Check No.	

Fig. 28. Compensation record.

Sparks—Because they will often fly in so many directions at once, and because they sometimes travel for a considerable distance, sparks from cutting or welding must be watched closest of all to make sure they do not set fires. A spark is really a little ball of glowing metal oxide and some of the larger ones may retain enough heat to start fires for several seconds after landing.

Sparks which fly from welding work do not usually travel far unless there is wind or a strong draft. They are harmless enough if combustible materials are not too close to the work.

Cutting produces by far the heavier shower of sparks. The cutting sparks travel the farthest and stay hot longest because of their larger size. Much greater precaution must therefore be taken when using the cutting torch.

Heavy sparks from cutting work may sometimes travel as far as 25 or 30 feet away from the point of cutting. They can readily set fire to light materials such as excelsior, paper or oily rags. It goes without saying that if

PAY-ROLL REMITTANCE VOUCHER

Company or Check No.________

Employee's Name________________________ Employee S.S. Acct.No.________

Received from ________________________
(Employer)

For Earnings to ________19___ Amt.Earned $________

Hours Worked: ________ $________

Regular________ ________ $________

Overtime________ Deductions:

Total________ F.O.A.B.Tax $________

________ $________

________ $________

________ $________

Total Deductions $________

________________________ Net Amt.Herewith________
(Employee Sign Here)

Fig. 27. Payroll remittance voucher.

sparks should fall into containers holding flammable liquids, quick and dangerous fires would be the result. Several fires have been started by sparks falling into unprotected oil-soaked engine pits.

But it is most important to realize that sparks which fly away some distance or roll along the floor may sometimes cause smoldering fires if they come into contact with materials that do not ignite readily. Even the experienced welder knows how easily cotton gloves start smoldering due to sparks flying from the work. In the same way, sparks which fall on things that will burn, even though some distance away from the welding or cutting, can also cause smoldering fires.

Smoldering fires may start by sparks getting into cracks in floors and woodwork, or by sparks lighting on materials such as rags, tarpaulins, paper wrappings, wood chips, scrap lumber and worn cushion pads. Sometimes these fires go out, but sometimes they continue to smolder and may shoot up as long as a half hour later.

Every foreman in charge of welding or cutting work knows that when this work is a part of regular production or repair operation, and is carried on in the same location time after time, there is small likelihood of fires being started. There are a number of reasons for this. In the first place, fire hazards are usually eliminated before welding or cutting equipment is in-

RECORD OF COLLECTION ACTIVITY

Form C1 Mailed ______ Covering ______ $ ______
Date Month Amount

Form C2 Mailed ______ Covering ______ $ ______
Date Month Amount

Form C3 Mailed ______ Covering ______ $ ______
Date Month Amount

Telephoned Cust ______ Promised ______

Telephone Cust ______ Promised ______

Personal Call ______ Promised ______

Record of Payments: ______ ______ ______
Date Amount Balance

______ ______ ______
Date Amount Balance

Terms Changed: ______ Account Closed ______
Date Date

Fig. 28. Record of collection activity.

stalled. Any hazards that may be overlooked at first are generally taken care of after a short time, and the welding or cutting work is then well safeguarded.

On the other hand, welding or cutting work done with portable equipment in temporary locations is much more apt to cause fires, unless suitable precautions are taken. For one thing, the equipment is used in a wide variety of places—quite often places which cannot be made as proof against fire as a welding shop. Sometimes the fire hazards are not out in plain sight and are known only by the local foreman or superintendent. Often an outside contractor brings in equipment, and his men may hesitate to ask for the necessary assistance in preventing fires. Demolition work presents a serious problem of fire prevention due to the general disorder and litter common on such jobs.

The facts are that of all fires caused by welding and cutting work, about 80 per cent are caused by cutting in some place other than a permanent, safeguarded location. This will explain why the following recommendations on preventing fires are chiefly about sparks and slag from cutting work.

The facts, too, are that welding and cutting fires are preventable. Companies who encourage their foremen to enforce these recommendations have as low a fire loss record with their portable equipment operated in a permanent location.

Preventing Fires—The safest and surest rule to follow in preventing fires is to—

Keep flames, sparks, molten slag and hot metal from coming in contact with materials that will burn. . . .

Take no chances. Fires can get the best of you at times even if you are prepared to put them out.

Never use cutting or welding torches where sparks or an open flame of any kind would be a hazard.

Before you cut or weld in a new location for the first time, always check with the nearest foreman or superintendent in authority . . . he may know of some serious fire hazard that you might fail to guard against.

Use sheet metal guards, asbestos paper or curtains, or similar protection to keep sparks close in to the work being done.

If welding or cutting is to be done over a wooden floor—Sweep wooden floors clean and wet them down before starting work.

Be Prepared to Put Out Fires—Always be ready to put out any fire promptly with fire extinguishers, pails of water, water hose or sand . . . have a helper, or one or more extra men if necessary, on hand ready to extinguish a fire.

If the place in which cutting is to be done is provided with sprinklers—Maintain sprinkler protection without fail while cutting or welding is being done . . . it is of special importance to make sure sprinklers are working during extensive repairs or building changes. If sprinklers must be shut down for a time, have this done if possible when welding or cutting work is not in progress.

Keep a man at the scene of the work for at least half an hour after the job is through . . . have him look carefully for smoke or fire before leaving. Don't forget that heavy sparks from cutting operations sometimes fly 25 to 30 feet or more and hold their heat for several seconds after landing.

Practicing Safety with the Other Fellow's Property—An increasingly large number of compressed gas cylinders and other containers, the property of the manufacturer, are damaged in customers' shops because operators thoughtlessly use them to strike arcs. This is a very dangerous procedure, entirely apart from the material damage to the cylinders. All operators should be cautioned against this practice. To reinforce such personal solicitation it is suggested that a warning card be displayed suitable for tacking to walls or bulletin board, with the following wording prominently displayed:

DANGER
DO NOT STRIKE ARC
ON ANY COMPRESSED
CYLINDER

Safety directors where employed in larger shops will appreciate the seriousness of this suggestion and are urged to assist their customers in instructing their personnel, and particularly warning them from unsafe practices.

Safety Committees for the Small Job Welding Shops—A small job welding shop with limited personnel is considered as being an organization where employees ordinarily work in one department and where the manager or owner has no assistant to whom he can delegate partial responsibility for various problems of management. Such a plant or shop should have what is known as a "shop safety committee". This committee may be composed of three or more of the following: (1) Manager (a person in the shop with the most authority); (2) Superintendent, (3) Foreman (one or more); (4) Welder (one or more); (5) Safety Engineer, and/or the Purchasing Engineer or Office Manager. The foreman and the welder should rotate in office.

The duties of a plant safety committee may be outlined as: (1) Cover the entire field of accident prevention. (2) Handle all legislative and executive matters. (3) Fire protection and sanitation inspections. (4) Inspections for hazardous and resulting recommendations. (5) See that new and old employees are properly instructed as to the hazards of their respective jobs. (6) Meet at least once a month. (7) Keep an orderly and constructive record of the minutes. (8) Turn the minutes over to the manager or other designated authority for review. (9) Invite the manager to attend at least some of the meetings. His presence will indicate his support. (10) Type, write or print safety bulletins when as and whereas necessary and display them

RECORD OF COLLECTION ACTIVITY

Form A Mailed ____ Covering ____ $ ____
Date Month Amount

Form B Mailed ____ Covering ____ $ ____
Date Month Amount

Form C Mailed ____ Covering ____ $ ____

Telephoned ____
Date Promised:

Telephoned ____
Date Promised:

Telegraphed
Telephoned ____
Date Promised:

Personal Call ____
Date Promised:

Record of Payments: ____ ____ ____
Date Amount Balance

____ ____ ____
Date Amount Balance

Terms Changed: ____ Account Closed ____
Date Date

Fig. 29. Another record of collection activity.

prominently on bulletin boards. In these bulletins promote "safety education". Brief month by month notices may be setup and detailed or briefly commented upon as follows—

JANUARY—Maintenance and Repairs

The maintenance men who keep the plant safe for the rest of the organization are themselves exposed to many hazards. They should be reminded to: Stop all machinery before lubricating or making repairs. Be sure that electric lines are dead.

FEBRUARY—First Aid

Why do men delay reporting minor injuries for first aid treatment. Popularize the first-aid department.

MARCH—Adequate Instruction

"Ignorance of the law excuses no one", is an old legal saying. Ignorance of safety rules won't keep a man from accident. Every worker is entitled to thorough instruction in the safe methods of working and the shop foreman should make sure his welders and helpers understand the instructions before going ahead.

APRIL—Housekeeping

Keeping the shop in a neat and orderly condition is a never-ending job—

it will help to check frequently for dirty areas, obstructed aisles, defective floors, broken stair treads, etc.

MAY—Hand Tools

Hand tools receive a lot of punishment, even when used by skilled, careful workmen. They can't be inspected too frequently if all defective tools are to be detected before they cause trouble.

JUNE—Health

Summer heat brings discomfort. Emphasize the precautions essential to personal hygiene. Explain the value of salt tablets in maintaining health in hot weather.

NOTE—Follow through on the remaining months in much the same order. Topics may be covered to include (1) Electric Equipment (2) Preparation for Winter (3) Personal Protection (4) Heating and ventilating equipment (5) Inventory—in connection with this last heading it is a fact that the end of the year is the time for stock-taking and a safety department might well check up on its organization, its equipment, its successes and its failures. Changes or additions that will increase the effectiveness of the program may be considered. Start work on plans for the new year and invite suggestions for new safety activities.

Never in the history of our country has there been a greater consciousness of safety. We are spending billions of dollars in order to save our country and its democratic ideals. Safety on the seas, safety on land and in the air is a paramount issue in the minds of the American people and its government. In order that the seas, the land and the sky are prepared for defense of our country the mudsill of it all is on the shoulders of the industrial workers. If this be true, then it is the patriotic duty of both the employer and employee to magnify the importance of Safety. Speed is the cry of those interested in the production of war materials. Haste is necessary, and because of it there are more opportunities for accidents. An injured workman cannot produce. We should, therefore, determine that safety shall, at all times, prevail in our plants.

"We should think and act for safety"!

Chapter II—Organization of Garage or Service Station for Arc Welding

By Clarence McClellan

Director of Welding, McClellan & Sons Super Service Station, Menomonie, Wisc.

Clarence McClellan

Subject Matter: The garage located in a community under 10,000 population has a better chance for success in arc welding than the garage located in a larger community. The shop described has sufficient equipment to do a wide variety of automotive jobs as well as outside welding which amounted to 38 per cent of the total welding business.

The advancement of welding in all fields of production and construction of machinery, including the automobile, has placed the garage or service station, whose business it is to repair and maintain automobiles, trucks, and busses, in an important place as an outlet for arc welding in maintenance and repair.

The garage or service station located in a community of under 10,000 population has a far better chance for a business in arc welding than the garage located in a larger community. This is based upon a national industrial survey conducted by "Motor Service" magazine which points out that welding ranks seventh in the list of importance of jobs done by the garage in a community under 10,000 and twenty-fifth in communities over 10,000. There are 13,000,000 welds to be made on machinery this year (1942), and the garage or service station which has arc welding and knows how to use it will be in line for a big increase in business in 1942 and succeeding years.

The advancement and streamlining of practically all of our social and industrial life has shortened the distances between supplier and consumer, consequently the community that can produce the service and commodities that the public wants is the community that will get their business. This eventually leads to the statement that the larger the community, the more and varied the service rendered taking in all service rendered in a community's social and industrial life. Consequently, since repairing and construction are the units which keep the community's wheels turning, arc welding as a practical speedy method of repair and construction, quite naturally builds up a community, because the public does not have to go elsewhere in order to have its work done; and since arc welding has no bounds as far as applying it to industrial fields, it falls upon the shoulders and ability of the garage or service station personnel to know what can be done with this process.

The saving of time, money and material made possible by arc welding in repair, maintenance and construction is a community builder just as important in its place as educational facilities are to children and adults. With

smaller and smaller profits coming to any business on a basis of volume of work done, it is going to be essentially necessary to offer faster and more efficient service in order to survive competition. This leads to redesign and faster methods of construction and repair and the logical answer is arc welding.

We have developed socially primarily because of advancement in communication, transportation and production based upon scientific research, and in this period of war and unrest we cannot go backward. As an aid to this advancement, arc welding as a means of repair, maintenance and construction in urban and rural life, will be called upon to do a great deal in maintaining this standard of social and industrial activity and advancement.

Basing our belief in the foregoing, and not looking just at the period of unrest that we are now going through, we have organized our service station for arc welding on a long-term basis. The operating divisions are the basis for conduction welding in the shop. They are: Production (material and equipment actually needed to produce arc welding in the shop), selling, research, accounting and personnel. All of these operating divisions go into the operation of the business; all are closely coordinated and none operates as an independent unit completely independent within itself.

The well organized and well equipped shop is the shop that eventually gets the business and the profits. The main field of welding work in the shop is repairing and maintenance of automobiles, trucks and busses, and this field alone is large. Listed below are automobile parts that our service station repairs by arc welding. They are: motor blocks and heads, valve covers, fly wheel housings, bumpers and bumper brackets, steering gear cases, steering gear brackets and tubes, steering gear housings, hoods, hood handles, running boards, running board braces, fenders, fender braces, rims, wheel hubs, hub flanges, brake drums, frames, spring brackets, motor supports, spring shackles, shackles, brake levers, brake pedals, brake shoes, brake bands, brake cams, axle shafts, rear axle housings, torque tubes, inner brake or backing plates, universal joint casings, flanges for universal joints, gear shifting forks, shifting levers, transmission housings, transmission covers, clutch pedals, clutch release levers, clutch pedal adjustment links, clutch pedal shafts, clutch pressure levers, clutch pressure plates, clutch cover plates, tail light supports, tie rods for head lights, head lamp housings, magneto mountings, spark levers, distributor drive shafts, oil pump cases, drain plugs and washers, oil pans, muffler pipes, exhaust pipes, exhaust manifolds, fuel tanks, foot feed pedals, water pump shafts, water pump housings, water pump covers, water pump impellors, radiator shells, overflow pipes, radiator connections, radiator tanks, baffel plates, outlet pipes, fan blades, fan pulleys and parts, fan hubs, cam shaft gears, crank handles, starter housings and parts, flywheel housings, frames, cowels, cross members, carburetor castings (cast iron), dash panels, doors, and wheels.

In addition to these jobs in the automotive field, the garage does considerable outside welding which amounts to 38 per cent of our total welding business, and the outside has shown the greatest business percentage increase in arc welding. It has grown from 18 per cent of the total arc welding business in 1938 to 38 per cent of the total welding business as of December 31, 1941. All welding business (arc welding and oxy-acetylene welding) has increased 104 per cent since December 31, 1938. Listed below are typical jobs in maintenance and repair by arc welding that our service station does outside of the automotive field. They are:

Farm Machinery—Building up and hard-facing corn shredder knives,

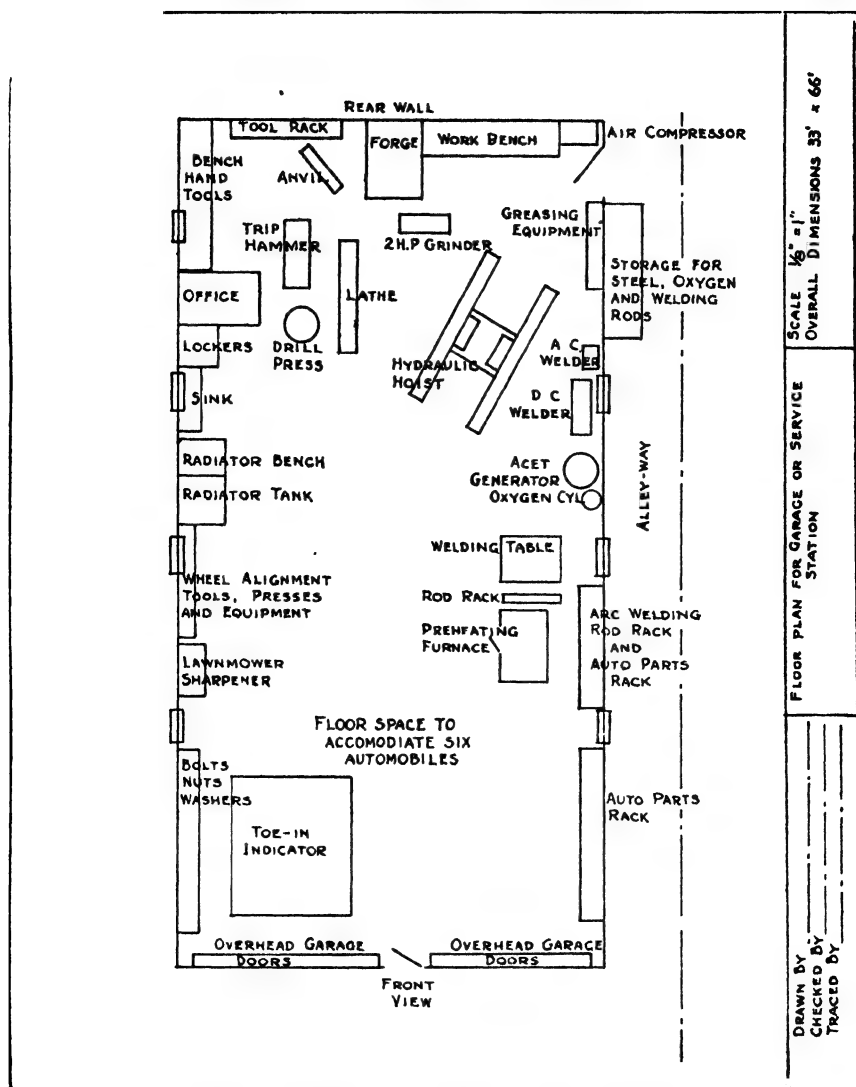



Fig. 1. Floor plan for garage or service station.

repairing binders and parts, welding on plow points, hard-facing plow shares, welding blower fan blades, silo filler knives, corn knives, corn planter shoes, cycle bars and heads, cultivator shoes, spring tooth harrows, drill parts, water tanks, cultivator levers, hay forks, hay pulleys, tractor cleats, hay hammers, disc blades, plow beams, mold boards, manure spreader wheels, drive gears and castings, horseshoes (toe calks and hard-facing), mower parts, threshing machine shafts, and cylinders, combine parts, corn picker parts, hay tracks, manure carrier buckets, seeder parts, wagons and parts, drag teeth, hay loaders and parts, hay bailing equipment, potato diggers, steel baskets, shredder rollers and shafts, milking stools, milking machine parts, aluminum milk receivers.

Household Equipment—Vacuum cleaner parts, spraying equipment, cooking utensils, stove castings, range doors, range lids, washing machine tubs and gear cases, washing machine rollers and wringers, toys, bicycle frames, sprockets and forks, lawnmowers, lawn rakes, hose reels, grass catchers, motor driven lawnmowers and parts, baby carriages, furnace sections for home heating plants, steam pipes and hot water radiators.

Functional Machinery—Water pumps for boilers and parts, can conveyors for creameries and condensories, power hammer castings and dies, hydraulic turbines, (building up, welding and coating with stainless steel).

Miscellaneous Work—Thawing water pipes and mains, renting arc welder to construction companies, consulting service to power companies on welding vertical and horizontal cast iron and steel turbine runners.

Redesign of Existing Structures—Redesigning motor bases and castings to welded steel construction, redesign of framework for doors, redesign of wheels and pulleys from cast iron to steel arc welded construction on threshing machines, silo fillers and tractors, redesign of cast iron wheels to steel construction for rubber tires.

Outside Welding Not Classified—Creameries, condensories, stainless steel milk tanks, steam pipes, monel metal tanks, filler machines, piping (milk) cooling equipment, storage tanks; crusher maintenance, building up worn manganese steel crusher jaws, dump boxes, crusher castings and frames, tracks, and conveyor belts; brick yard equipment, hard-facing pug mill augers, pug mill knives, clay feeder shoes, clay car wheels and axles, pug mill parts and castings.

The welding equipment which we find necessary to have in the shop in order to take care of all the classifications of welding above is listed below along with the prices on a basis of reproduction new, using 1939 as an average price year for equipment.

Item	Price
One 200 ampere motor generator dual control arc welding machine with 50 feet of number 2 cable, electrode holder and 2 arc welding shields	$ 525
One 250 ampere A. C. transformer with 50 feet of number 2 cable, electrode holder and 2 shields	255
One arc welding table equipped with curtains and ventilating equipment	35
One 200 ampere gas engine driven arc welding machine equipped with 180 feet of number 2 cable, electrode holder and 1 shield	700
One lathe, 16 inch swing and 8 foot bed motor attached	900
One 50 pound automatic acetylene generator	125
Two oxy-acetylene welding torches, 1 cutting head, 1 cutting torch, 70 feet of heavy duty hose with 12 feet of leader hose, 2 pairs of welding goggles, 1 pair of chipping goggles, gloves and lighters	235
Oxygen and acetylene cylinders for outside welding are furnished by the gas supplier.	
One 2 H. P. production grinder	270
One 250 cubic foot air compressor	290
One portable grinder ½ H. P. motor	60
One portable sander and polisher ⅓ H. P. motor	60
One drill press, 16″ plate will handle 1″ drill	275
Total Welding Equipment	$3730
One ½-ton pick-up truck	750
Total Equipment	$4480

In addition to the above mentioned machine tools, there are hand tools and materials which are necessary for the operation of the garage as a whole and arc welding as a unit. They are: work benches, open-end and box wrenches, pipe wrenches, monkey wrenches, screw drivers, hammers, wire brushes, chipping hammers, vises, tongs, steel racks, storage sheds for steel, oxygen, acetylene and welding rod, bolts, nuts and washers and bins for these, welding rod racks in the shop, chain hoists, preheating torch and preheating furnace, jigs and fixtures. The total for the above amounts to $1575.

Additional garage equipment such as wheel alignment equipment, trip hammer, forge, anvil, hydraulic hoist, toe-in equipment, greasing equipment, radiator bench and tank, lawnmower sharpening equipment and auto parts amount to $4260.

The total shop equipment for all units amounts to $10,315.

Along with the necessary equipment, hand and machine tools necessary for producing arc welding in the service station, there are a number of other factors that must be taken into consideration in order to actually have arc welding function properly. They are:

Appointment of a Welding Foreman—It is essentially necessary to appoint someone to be in charge of all welding activity in and out of the shop. The foreman must be given authority to act and should not be hampered with too many other activities in the shop. This will be brought out later under accounting for each unit and the responsibility that rests with the foreman. We have foremen for the major operating units of the shop and we experience no trouble and the employees experience no trouble in knowing who is in charge and from whom to seek help or information.

We have made it a shop policy that every foreman have three years' trade experience in his major operating unit, a high school education or has completed courses in a vocational school in shop mathematics, physics, chemistry pertaining to materials and bookkeeping. We have found through experience that a foreman who possesses the foregoing qualifications advances faster and grasps new ideas faster than men without these qualifications. There are, however, exceptions to this policy and one of our foremen does not meet these requirements but has the ability and interest to go ahead and will in time acquire the necessary educational requirements. It is difficult to get men to go to school, but like anything else the starting point is the hardest to overcome. Once the men start a required course and find out how much they are lacking, and how much they don't know it is an easy matter to keep them going.

The foreman, besides knowing his subject matter, must be a leader of men and a teacher. He must be able to lead them to the output of work that we demand and yet must keep their respect. We have found that a foreman who drives men will not have their trust and the men in turn will lie and evade him whenever they can and will avoid working under him when possible. This causes a drop in output of work and a general lowering of morale among the employees. The foreman must also be a teacher in terms of demonstrating the correct method of doing jobs in his field. This is especially true with new men who have had no previous work experience in the operating unit in which they are working, and older men who are not familiar with newer methods.

Selection of Arc Welding Machines—The shop has three welding machines, a 200-ampere motor generator D. C. set and one 250-ampere A. C. transformer both of which are stationed in the shop. For outside welding

Job Number 32 Fishplating truck frame
Super Service Station

Customer listing and job filing card
Customers Name ______ Date ____19__

Material Used	Amount	Selling Price	Time For Operation	Amount
2-3/8" steel plates 6" x 6'	180#	.06¢ #		$10.80
Oxygen and Acetylene for cutting plates	20 Cu.	.05¢	½ hour	$ 1.63
Arc Welding rod no. 7	5#	.20¢#		$ 1.00
			1 hour for handling steel	$ 1.25
			2½ hours welding	$ 2.13
Current for welder	20 kw	.12¢		$ 2.40
Labor change at $1.25 per hour			Total------	$19.21

Fig. 2. Sample customer listing and job filing card.

we have a 200-ampere gas engine driven machine. The machines are sufficiently large to take care of 95 per cent of all our welding in and out of the shop. There are times, however, when we could use a 300-ampere gas engine driven welder very nicely on such work as thawing water pipes and welding heavy sections of turbine blades. The 200-ampere D. C. welder and the 250-ampere A. C. transformer are used in the shop and we find it necessary to have them in order to take care of rush periods of welding and general speed up of output of welding jobs by putting two machines and welders on the same job.

Our experience has proven to us that it does not, in any way one wishes to look at the problem, pay to "build your own" gasoline engine driven welder. There are 200-ampere gasoline engine driven welders now available at approximately $450. No one can possibly buy a welding generator, secure a motor and governor and build an arc welding machine under $600. We know this from our own experience; in fact our gas engine driven welder cost us approximately $700 and then it was not up to the point of perfect operating efficiency. Lack of experience is the greatest drawback in "building your own" primarily because of lack of necessary building experience in this field and adequate knowledge of design and proper motor sizes for different sizes of generators. If we find it necessary to secure another gas engine welding machine, we will buy it from a reputable concern whose business it is to manufacture them.

Selection of Hand Tools, Machine Tools and Benches—The number of hand tools, machine tools and benches needed will depend upon the amount and type of work done. We in the auto shop find that the line of hand tools and benches ordinarily in a well-equipped service station will adequately serve arc welding. There are, however, a few machine tools that we find necessary in order to prepare and finish welding jobs. They are: a lathe 16-inch swing 8-foot bed, drill press with a 16-inch plate which

will handle a 1-inch drill, floor shear for cutting steel (not shown on the floor plan) up to ½-inch, power hacksaw (not shown on the floor plan) and 2 horsepower power grinder. These machine tools adequately take care of all preparation for welding and finishing the job after welding. We are forced at times to turn down heavy jobs because our machine tools will not handle them. However, when the volume of this business is sufficient to warrant investment in heavier machinery we will purchase the necessary equipment.

Selection of Welding Electrodes—All welding electrodes used in the shop conform to the American Welding Society specifications. No bare or lightly covered electrodes are used except in the case of building up manganese steel crusher jaws and manganese steel in general. Even in training mechanics in welding we do not use bare electrodes, primarily because bare electrodes do not have sufficient resistance to shock and bending stresses. We find it highly advisable to use welding electrodes that follow specifications and produce maximum strength of deposited metal. Then, too, covered electrodes are probably the only type which will be used in the future. We entirely discount the idea, and our training program for our own welders does not substantiate the statement, that it is better to train a man on bare electrodes first because he will find it necessary to develop more skill in order to run this type of rod. We have not found the transfer to training, whatever amount there may be, of sufficient value to train men with bare electrodes. We use the largest electrodes that the job will accommodate, and the various sizes that we keep in stock are: 3/32-inch, ⅛-inch, 5/32-inch, 3/16-inch and ¼-inch. The electrodes cover welding of cast iron, steel to cast iron, aluminum, bronzes, brasses, copper, high and low carbon steel and general purpose repair electrodes. Hard facing electrodes are carried in small quantities because of the large outlay of money necessary to stock them in quantity.

Provision for Power—Power for the A. C. transformer and D. C. motor generator set runs to the machines on separate power lines. The A. C. transformer requires 220 volts, 60 amperes single-phase current while the D. C. set requires 220 volts 60 amperes 3-phase current. All machines in the shop have individual motors and if the motors are 2 horsepower or more, independent lines supply them. We have had to change the wiring in the shop completely in order to take care of additional electrical equipment such as the two arc welding machines, the trip hammer which has a 2 horsepower motor attached, the drill press, grinder and additional electrical tools such as the portable grinders and sander.

Provisions for Moving Equipment—No business remains static; it either goes up or down, and when a business begins to expand it takes some time before the management realizes that a change is going on. We have made every effort to watch these changes and have made our equipment portable in order to meet one phase of expansion. We are able to move our welding equipment by just disconnecting the power line to the machines and pull them wherever we desire. Many times it is much less expensive for the customer to have welding equipment moved to the job instead of the job to the equipment.

Water Supply, Lighting, Arrangement of Equipment, Jigs and Fixtures—Water supply is a necessity for any welding or auto shop not only for work in connection with automobiles but also in welding. Fire protection is a necessity as is cleaning flux from welds such as aluminum castings where the flux must be removed as soon as the welding job has cooled to room

temperature. This is done with a wire brush and warm water which is supplied from an automatic hot water heater. In order to have adequate protection from fires of which there is always a danger because of sparks and molten metal from welding and cutting, we have a hose and nozzle next to the welding booth. In this way water is available at all times and all one has to do is to turn on or open the water valve on the line. This safety or fire prevention equipment, while not much, has put out 3 fires for us over a 3-year period which might have been serious.

In arranging light for the shop, we have eight 100-watt overhead lights for general work which is readily seen and "floor lamps" and drop cords for tight places and work which is not readily seen. A poorly lighted shop, aside from natural light, can hardly be called efficient. Much time is lost and indirectly output goes down if adequate lighting is not available. Burden is always a factor in any shop and our lighting bill has been cut 21 per cent over the previous arrangement of four large overhead lights, "floor lamps" and drop cords. It is not necessary to have the overhead lights on when the mechanic is welding a fender or repairing a muffler or working where the overhead lights cannot reach. In a place of this kind a drop cord is used. The mechanic's morale is also a factor and one cannot expect the maximum on any job if it is difficult to see because of shadows or dim light.

The arrangement of our equipment is in terms of efficiency. The shop floor plan, (See Fig. 1), illustrates this point; all of our machine tools are located in the back half of the shop. This saves many steps and time in moving from one machine to another or transfering work from one machine to another or from machine to bench. Also all hand tools used in connection with the work being done are on racks on the machine or bench. The tools are on hand all the time and this is definitely a morale booster and an aid to faster output. If a mechanic finds it necessary to cover the shop looking for tools or to ask help for moving a welder, (if they were not portable), much time and energy would be lost in this type of non-productive activity. We can work faster and produce more in a shorter period of time and have better working conditions, and, consequently, higher wages just because the equipment and tools are arranged together for the work being done.

Jigs and fixtures play an important part in the output of our welding department; not only do they help in keeping up the morale of the welding operator by aiding in the quick alignment of parts to be welded, but the saving of time which in turn keeps the cost per job at a minimum level, is equally important. The welding department has on hand at all times, located near the welding booth, different thickness of small steel plates for alignment, heavy and light sections of angle iron for shafting, X blocks, "C" clamps, wedges, small "I" beams, bars, boxes of sand for annealing parts and various sizes of fire brick; all of which aid in faster production on the job and eliminate loss of time.

Ventilation, Arc Welding Booth and Signs—The arc welding electrodes used in the shop are heavily coated and while the operator or mechanic is welding, a considerable amount of smoke and gas is given off which, if not carried away, would collect inside the shop and cause considerable irritation to the employees and customers, plus endangering their health. State industrial commissions are becoming aware of this hazard and although the American Medical Association in an article published approximately a year ago in "The Journal of the American Medical Association" does not say that any injury to one's health has been recognized as yet from the large amount of dangerous nitrous oxide gas given off during the welding process,

Work Turned Down Slip

Customer John Doe Date 4.211942

Job Turned Down	Reason
Rebuilding worn shafts and splines 6 shafts 5½' long 4" in diameter estimated cost of job $60.00	Need milling machine for cutting splines and lathe not large enough to handle the work

Fig. 3. Sample "turn down" slip.

we have taken no chances and have installed a ventilating fan directly above the arc welding table. The fan not only carries off the gas and smoke from welding, but helps carry off fumes from the radiator bench and soldering table, coal smoke from the forge and oil and exhaust fumes from the lathe and automobiles run in the shop. The ventilating fan is much more efficient if a hood surrounds it and is lower than the fan. The hood is 6 feet by 3 feet, the fan runs at 1800 revolutions per minute, displaces 3000 cubic feet of air per minute and is 16 inches in diameter.

The arc welding booth has been enlarged from a table 3 feet square to a table and curtains 6 feet by 3 feet. This is a direct result of more welding business during the past two years, and is a means of selling welding because we can invite our customers into the booth and let them watch the welding on their equipment or parts. This is one of our best selling aids and will be discussed under selling welding for the service station. The welding table is surrounded on 3 sides by dark curtains which can be raised or lowered at the operator's desire. This is definitely an improvement over our former booth which had curtains 5 feet high and could not be moved. We had considerable trouble with this arrangement in that moving automobiles would catch the curtains and tear or rip them off the frame. Then, too, with the former method of shielding the arc booth, the curtains were burned badly during the numerous cutting operations that we do with oxy-acetylene cutting torches. Now, when arc welding is being done on the

welding table, the curtains are lowered from the ceiling of the shop to the point where they completely surround the welding table and no rays from the arc escape to cause annoyance and eye irritation from flashes. Also this brings down the cost of operating the welding department in that during the past two years we have not had to replace the curtains while with the former method it was necessary to replace the curtains every 6 months. The curtains are 4 feet high and 6 feet long. The welding table is waist high, has a cast iron top coated with spatter film so that spatter from welding electrodes does not adhere to the plate. A ground connection is bolted to the table to produce a good circuit.

Many times we find it necessary to do welding outside of the welding booth and in order to avoid possible injury and flash burns from the arc we have had a number of signs made up which read "DANGER, DO NOT WATCH THE ARC". The signs are posted nearby where the welding is being done and so that everyone can see them before becoming curious. This is a customer service and protects us to a degree from liability in case of any serious injury or accident that may occur.

Preheating equipment is a necessity for the shop because there are castings such as face plates for clutches, aluminum outboard motor castings and aluminum heads which must be preheated evenly and slowly in order to keep them from warping during preheating, welding and cooling. The preheating furnace operates on city gas alone and is a definite improvement over our former furnace which operated on city gas and compressed air. With the "new" furnace there are no fluctuations in the temperature during the preheating and cooling operations. The furnace is large enough to hold approximately 100 pounds of tools and the temperature is measured by a pyrometer. The preheating furnace is a life saver for preheating castings up to 100 pounds.

Training Mechanics in Welding—In July of 1939, three of our men left our shop for employment in west coast shipyards. These men were the backbone of our welding department, and because we could not compete with the wages paid by the shipyards we could not hold them. Soon afterward we advertised in newspapers in surrounding communities for three welders to replace the men who had left, and strange as it may seem none of the men who applied were able to pass vertical and overhead qualification tests and as a result we did not hire them. Before this time we had paid some attention to training welders for our shop, but not enough to keep a few men in the other operating units trained well enough to take over in case of just such an emergency. As a result of this experience, we formulated the basis for our training program. We do not attempt to train a mechanic who does not want to be a welder, primarily because no one can teach another person anything unless the person is willing to learn and is interested in the work. We have even found it necessary to train the men who come to us from other places even if they have been welding before or have received an introduction to welding from a vocational or trade school. We do prefer, however, a person who has had training in the basic principles of welding because they are ready to advance and grasp the new material faster than a man with no previous training. We require certain qualifications for welding and they are a high school education, with courses in chemistry, mathematics, physics and although not required but desired, bookkeeping experience or a course in bookkeeping. If we hire a person for welding who does not meet these requirements we arrange with the local vocational school to give him the courses needed. Not only does this benefit

the employee and employer, but the country as a whole in having a person trained in a number of fields, which makes him a more valued employee and is definitely of value toward job insurance in that the employee is harder to replace and he himself will find, if he so desires, future employment much easier.

We have realized for the past two years that all of us will be spending more time in school and by this we do not mean the group from 6 to 18 years, but all adults in order to keep up with technological, functional and social change. Most of our employees attend night school off and on in order to keep up and advance themselves.

Training people in any field presents many problems that are dealt with in teacher training courses, but do not assist us to the degree that we expect. In solving this problem of training, we first determine what the employee or prospective employee already knows and can do. This is determined by placing him on a probationary period in all the operating units of the shop on the basis of no or limited training before his employment by us. If his mechanical ability is good, if he is co-operative, and will take and follow instructions, he is allowed to select his major unit of work. This probationary period for all new employees, if we are not familiar with their background, varies from 2 to 16 weeks, depending upon the employee's advancement, through the operations that we require for each unit.

The basis for our operation selection is based upon the jobs that we do in each operating unit of the shop. We have analyzed all the jobs that we are able to do in each operating unit and have broken these down into the various operations that go to make up the job as a whole. The operations are then grouped according to frequency or the number of times the operation is done in our shop, significance, availability and economy. The operations selected on this basis are practically fool-proof in selecting the right operations to teach not only the portion of the trade that our shop covers but for the field as a whole and wherever it presents itself.

We have never taught welding during the past two years, on the basis of teaching it as a trade complete within itself, but have been teaching welding as a part of each trade. The welding done in the auto shop is vastly different from the welding done in shipyards. The American Welding Society has turned in this direction in an article in the November 1941 issue of "The Journal of the American Welding Society", pages 781-783.

After the mechanic has had his introduction to welding and he is able to run satisfactory beads, knows machine adjustments, and knows current values, he is taught the operations necessary for the welding in the shop. The mechanic proceeds to do operation number 1, and lists the number of hours that he has worked. The mechanic is issued a progress chart and he checks off the operations only after the welding foreman is satisfied that the mechanic has mastered the operation and is able to repeat the same operation with the same skill or quality of work on an actual job. In operation number 1, the mechanic will be welding 1/16-inch sheet steel, using a 3/32-inch electrode, straight polarity, rod composition range to 40 point carbon will contain about .07 of 1 per cent carbon and the welding will be in the downhand position. In operation number 2, the mechanic will be welding 1/8-inch steel, using straight and reverse polarity electrodes of 3/32-inch, 1/8-inch and 5/32-inch diameter; the rod composition will be under 40 point carbon and the welding will be done in three positions, downhand, vertical and overhead. During this operation, the mechanic will do more than one operation, in fact he will do nine operations in order

to complete operation number 2. He will be able, when finished with the whole operation, to weld ⅛-inch steel with $\frac{3}{32}$-inch rod in the three positions; the same with ⅛-inch and $\frac{5}{32}$-inch electrodes.

As the mechanic completes these operations and checks them off he is ready to go on to actual jobs that involve these operations. After the mechanic has completed all the operations on the progress chart he can do or qualify for 90 per cent of the welding jobs in the various operating units whose number is the same as the operation number.

The welding foreman plays a very important part in the training of our men. He is their instructor through their entire training period and has the confidence of the men being trained. This is important because when a mechanic in training makes a mistake on the job, the foreman is there to correct the error and leads the mechanic to avoid errors and yet keep up his interest and morale. The welding mechanics go through 23 training operations before they are ready for all the kinds of welding in the shop.

________________ Super Service Station

INVENTORY SHEET

Date__________19_____ Week Ending__________

Item	Amount on Hand	Supply low		Adequate		Order		Amount
		yes	no	yes	no	yes	no	
¼ round steel								
3/8" rounds steel								
½" rounds steel								
12 Gauge x 1"								
12 Gauge x 2"								
12 Gauge x 3"								
12 Gauge x 4"								
1/8" x 1" flats								
3/16" x 1"								
3/16 x 2"								
¼ x 1"								
¼x 2"								
¼ x 3" plate								
¼ x 4" "								
¼ x 6" "								
3/8" x 4.5 x6"plate								
220's Oxygen								
110's Oxygen								
100's Acetylene								
300's Acetylene								
100's 1¼x3/8 Carbide								
Flux number 2								
Flux number 3								
Flux Amalgam								
1/8 No 5 Electrodes								
5/32 No 5 "								
3/16 No 5 "								
1/8 No 7 "								
5/32 No 7 "								
3/16 No 7 "								
1/8 A.C "								
5/32 A.C. "								
3/16 A.C. "								
5/32 Aluminum Rod								
5/32 Monel Arc Rod								
Weekly Totals								

Fig. 4. Sample weekly stock record sheet.

This does not mean that a man can come to us with no previous experience in welding and go through these operations one right after the other and come out a finished welder. All during the period of training, the mechanics act as helpers for the qualified welders, and in this way they gain valuable and necessary experience which cannot be taught otherwise. The training period in welding ranges from 6 months to a year and even then more experience is necessary in order to qualify as an A1 welder for all the types and kinds of welding that come into the shop.

All through the mechanic's period of training, the foreman is there to supervise his work and show him shortcuts on many jobs. If the mechanic forgets or is unable to do a weld involving an operation that he has checked off on his progress chart, the foreman requires that the mechanic go back and do this operation over until there is no question about his ability to do the same operation on a "live" job. The men in training at all times receive a demonstration on the operation before they are allowed to go ahead and practice it. The demonstration covers the correct technique, proper machine settings, correct welding electrode, checking of equipment before welding, proper chipping procedure and related technical information about the deposited metal that is necessary to know in order to do the job.

The auto shop is not in a position to furnish expensive testing equipment such as a guide bend testing machine and tensile testing equipment. There are, however, effective tests that we use and they are the face bend test for ductility, the root bend test for penetration and the nick break test for defects within the weld itself. An ordinary blacksmith's vise is sufficiently strong for these tests. The qualification tests are made on 3/8-inch steel plate, the composition of which is approximately 40 point carbon and is the nearest material that we can secure for the type of work in the shop. The test welds are made on plates 6 inches by 8 inches, beveled at 60 degrees, with rod size root opening. The root edges of the weld are ground off so that a blunt edge 1/16-inch is made. After the test welds have been run in the downhand, vertical and overhead positions only with 5/32-inch reversed polarity rods, the test specimens are cut out of the center of the plates to the dimensions of 1½ inches by 6 inches. The beads are then ground off flush with the base metal and the backing strip is machined off flush. The specimens are then bent through 180 degrees or a U using both the face bend test and the root bend test. No cracks or undercutting are allowed. For the nick break test, we use the portions of the plates left over after cutting out the first two test specimens.

If the mechanic or potential employee, (depending upon his past experience), fails to pass these tests he is given time to go back and practice and the foreman points out his mistakes. This second try is allowed because experienced welders have the tendency to get "buck fever" when asked to make a test weld.

After the mechanic has finished the first four operations, he is given a text book on the metallurgy of iron and steel. This material deals with the freezing of solutions and generally what takes place in the metal during the molten, freezing and solid states. After a period of time, depending upon the mechanic's ability, we give him an oral test on this material. If he does not pass the test to our satisfaction, he is required to study until he does. Much of the discussion during the monthly meetings of our employees is on just this sort of thing and these meetings and discussions act as "pep" meetings for the men having difficulty with material.

With this information, the mechanic can foresee and determine the proper welding procedure and technique and is in a position to intelligently answer questions from men in authority for whom we do welding. It creates a very favorable impression and definitely sells our customers on our organization for welding.

In determining the proper joint design to use on our welding jobs and construction work, we follow the "Procedure Hand Book of Arc Welding Design and Practice", the material or information which comes under the section on "Procedures, Speeds and Costs" which include electrode sizes, amperes and volts to use and amount of rod deposited per foot of weld. We follow this material because of the wide variation in joint design and other information concerning welding. We in welding are feeling the "growing pains" that welding as a whole is now experiencing.

The foregoing on training mechanics in welding may seem long and involved, but we deem it necessary because we cannot hope to qualify as an A1 shop unless we know exactly what our men can do in this field, and in the last analysis, it is the shop reputation that goes a long way in selling the product. We no longer believe any mechanic or welder who comes to us and states that he is a welder. We find out just what he can do by running him through the various training operations and, strange as it may seem, seven out of eight welders who came to us for employment during 1941 failed miserably for our work. The cost to us to train a mechanic in welding who has had no previous experience amounts to $236.75. Not a small amount for any shop, but a very profitable investment. The average cost for men with welding experience amounts to $123.40. These are average costs and are not to be taken as the amount that it will actually cost within a few cents.

Two men who have left our employment have had no difficulty in qualifying for submarine welding. They left the shop in 1941 primarily because we could not meet the wages paid by companies with government work. When our men are able to secure employment on probably the most exacting type of arc welding, we are not wrong in our training program. It is our best insurance against poor workmanship and loss of our shop reputation. Since the start of our training program in the latter part of 1939 and beginning of 1940, we have had just three welding jobs that were not entirely satisfactory, and the reason for this was as much the fault of the customer as our own.

Progress and change are the life of any business and in order to encourage interest and development in the welding department and all other departments, we have what we call our "Profit Development Plan". The purpose of the plan is to pay the mechanics the profit that is realized on new methods and developments that they suggest and put into operation. If a person has something to work for he tends to work harder, his interest in his work becomes intense and he learns much faster. The plan is not difficult to put into operation; an example of its operation is as follows:

In September of 1941 one of our welding mechanics suggested that we change hard-facing rods from the tungsten carbide rod to one having a cobalt base. The cost to us with the tungsten carbide rod amounted to $5.50 per pound while the cobalt base rod amounted to $4 per pound; this was not the only factor however in adopting the latter rod. The amount of time to apply the rod was the same, the amount of rod used was practically the same and after having the application tested in actual plowing and road grading, the life and service of the latter rod was longer by 25

_______________ Super Service Statio

Bin Tag   Date ______ 19___

Items Taken	Amount
50 # number 5, 5/32 Arc Welding electrodes	50#

Items Returned	Amount
30# number 5, 5/32 Arc Welding Electrodes	30#

Total Amount Used 20#

Fig. 5. Sample bin tag.

per cent because of its toughness over the extreme hardness of the tungsten carbide rod. The plan was adopted and the profit of the first job which was $5 was paid to the mechanic. The job and application was listed in our profit development file cabinet under hard-facing. During the past two years, we have changed our profit development plan from just paying the mechanic the profit on the new methods that he introduces, by paying or giving him a raise and the profit on each development after he has developed five new methods or has improved and increased the profits to the shop. The file is checked over monthly and the raise in wages is automatic. The plan provides a check-up on the mechanic's ability, development and progress, plus giving the shop an overview of welding possibilities. No one loses, the shop and the mechanic gain and harmony is produced between employer and employee. All developments are discussed among the manager, foreman of the welding department and mechanic.

Selling Arc Welding for the Service Station—Every sale made in or out of the shop takes into consideration three principles regarding the customer and the shop. They are: The way to sell any product is to develop sound business policies. The customer is to be sold something to his advantage, and the selling process must be a live honest transaction. Alone, these principles governing a sale, do not suffice. The shop appearance is also a determining factor. During the course of our 8-hour working days or

40-hour work weeks, there are always a few minutes or half an hour during the day when a mechanic has "time on his hands". During these times our mechanics clean up their units and help clean up other operating units. The floor is swept, the tools are repaired or cleaned, painting on places where no one is liable to come in contact is done, walls are touched up, and general clean up work is taken care of. In this way, the shop is always neat, makes a good impression on our customers and produces better working conditions.

Our arc and acetylene welding equipment is cleaned monthly. The interior of the arc welders is cleaned of dust and dirt with the air gun, also cable connections are checked, and the electrode holder jaws are removed and cleaned of all spatter and foreign material. This policy of cleaning the equipment and shop so that at all times everything is clean and neat is one of our best selling aids.

Whenever the opportunity presents itself, we invite our customers into the arc welding booth and allow them to watch the welding on their own material and parts. This is definitely a selling aid in that it creates in the customer's mind, confidence in the shop and welding, primarily because he saw us do the work, the welding process was described to him while it was actually being done and the customer usually goes away with something new to him. This also helps to hold the customer to our shop, because at times they will shop around in other welding shops and if the method of welding differs from our method they will ask about it and compare it with our methods and as a result if the work being done for them in another shop is not explained, and is not as neat as our work, we have a steady customer.

In order to know and keep track of our customers, we have, during the past two years, enlarged and changed our customer filing cabinet. Formerly the customer cards listed the customer's name, the job and date, and the price of the job. Today, the customer cards list the customer's name, a detailed explanation of the job if over $3.00, the date and time required to do the job, material used, amount and price, (See Fig. 2). The cards are 5 inches by 7 inches. This is a consolidation with our customer job filing cabinet which will be discussed under pricing under accounting.

The operation of the customer file is simple. We have listed all of our customers alphabetically, and the welding work they have had done at the shop on the customer and "job filing" cards. Above the customer's name is placed the job number which in this case is number 32 which is for fishplating truck frames. We have listed the names and numbers of the jobs that we do in the shop. If at any time we want to look up a job, all we have to do is look up the job number and go through the filing cabinet and pick out all the cards with the job number attached and we have the history, price and material used on the job. This is an effective method of checking on our work, getting in touch with customers who have not brought work to the shop for some time and it also acts as a stabilizer for our output of work, because we known from the cards the amount of work each customer usually has and how often he brings work to the shop. The cards are also an effective aid in pricing work and will be discussed under pricing under accounting.

As a rule, three days after a welding job has left the shop, we send the customer a double mailing post card and on this card we ask him if the job is satisfactory, if he is satisfied and if not, what complaint he has to make. When a card comes back with a complaint that is fair and just, we file it with the customer's card and then send him a letter giving a

credit on his next job brought to the shop. These double-mailing post cards are mailed only on jobs that amount to $3 or more and mailing also depends upon the customer. This check-up has increased our business considerably during the past two years and has built up good will throughout our business territory, plus giving us a check-up on our work. Then, too, these cards block to quite a degree customer complaints. Since December 31, 1939 our welding business has increased 68 per cent and over a three-year period beginning December 31, 1938, 104 per cent. We attribute this to changes and progress in our work and methods of doing business, plus the constant check that we keep on our customers.

______________ Super Service Station

REQUISITION BLANK

Number________ Date______________ Order Number____
(Office Use Only)

Please Furnish material or service requested from

The ______________ Dept.

Charge to — Capital ________ / Reapirs ________ / Supplies ________

Signed ______________
Foreman

Approved ______________
Manager

Quanity	Unit	Catlog No.	Article	Cost	Total

Desired When ______ ______________ 19______

Fig. 8. Sample requisition blank.

We have tried various methods of selling and advertising our shop for welding and other work. We have dropped using, as a means of selling our products, theater slides and short, post-card advertising, hand bills and pamphlets for types of work, and radio advertising primarily because we derive very little business from this type of advertising. We are now concentrating on personal selling by making calls on our old and new customers. Our employees do considerable personal selling for us while off duty, primarily because whenever a new development is adopted or we start welding materials and parts not welded before by the shop, we make them acquainted with the process and if a discussion or a job comes their way while off duty, they immediately use their knowledge of the shop services to sell the person involved to have our shop do the work.

During slow periods in the shop, which come every January, February and first part of March, we are busy calling on our customers in the country and surrounding communities, collecting plow shares to be sharpened and pointed, mold boards that need patching, blocks and heads that have been injured by freezing and general work in order to keep our men employed. If we personally are not able to do this pick-up work, we send out our welders who are personally acquainted with our customers. This method of selling brings results; our welders have picked up on these personal selling trips as much as $75 worth of welding in a single day. The business is there and all one has to do is to go after it. During these selling trips we also act as a pick-up and delivery service for farmers who need food, parts or material from the city. We are going to be handicapped considerably and will probably lose our best selling aid for the duration of the war because of tire rationing. The pick-up-and-delivery service during the slow months of the shop was started in January 1940 and was so successful that we have used it the year around as much as possible. Even now, when we have had to cut down considerably on this service, our rural customers call the shop and ask when we are coming out their way and if we would bring parts or food to them.

For advertising the shop and the kinds of work that we do, we have three billboards on the main highways leading into the city. These signs acquaint prospective buyers with our complete service in auto repairing, welding and work. Besides this, we have a sign of the same color and lettering as those on the highways above the main doors of the shop to attract business, describe our service and establish our location.

We are not letting our selling methods down one bit, even though we are not able to do the things possible in 1940 and 1941, primarily because we will probably need considerable former business that we have had to let go because of national defense, which comes first in all considerations.

Research—Research or constant study is a definite requirement of the garage or service station. New developments and change go together. We of the auto shop are constantly studying new developments and trends which affect or will affect business and business possibilities, trends in repairing, changes and trends which will affect our administration of the business, percentages of total investments of new equipment, local trade opportunities, changes in methods of payments on new or used equipment, new welding techniques and new equipment and its usefulness to us. We are constantly watching developments which will affect business and our business in particular. Changes and progress in this field are definitely with the individual owner and the methods that we use to determine our business policies will be explained below.

When we discover that the shop is losing business because of insufficient equipment, we immediately determine how much business or work this field alone will bring in and how much work it will bring in, in connection with other equipment in the shop. This is determined from our "turn down" slips which are filed on an ordinary spindle. We have turned down during the past two years 54 jobs in which machine work and welding were required to complete the job. This indicates that we could have profited nicely by having a milling machine, shaper and lathe with a 24 inch swing and 16 foot bed. Our source of information is always available in the shop because whenever a job is turned down because of lack of necessary equipment or because we were too busy to handle it, the operating unit foreman

turns in a "turn down" slip to the office on which is listed the job turned down, the machine tools or equipment necessary to do the job and material needed. If we were too busy to do the job, the foreman writes "too busy" on the card and lists the job and customer's name, (See Fig. 3). The slip is then placed on the spindle for future reference.

Every three to six months we make a survey of the slips and if we find the amount of work turned down and the possibility of getting more work of the same type is good, we purchase the necessary equipment and hire additional personnel if necessary to do the work. This depends upon the cost of the equipment, its period of usefulness over a period of years and model in terms of possible change.

The business possibilities of new equipment are determined by surveying local industry and industry within a 25-mile radius of our shop. A few questions that we take into consideration are: Are our hand and machine tools adequate to handle additional work? Is the shop large enough or is there a possibility of building expansion? What can we do to build up a business in this line of work? What have we done in the past in new fields? Are we losing business because of lack of this equipment? Have we the personnel necessary to operate this phase of work? Have we the necessary finances to purchase the equipment or can we buy it on time? Straight thinking is a necessity, because if there is just an occasional demand for the equipment it would be better not to purchase and install it. Taking arc welding as a unit, it is easy to see that welding is definitely a standardized method of repair and construction and much more welding will be done in the future than has been done in the past. Then, too, the presence of the equipment attracts business and customers talk and indirectly sell the new field of work.

We have, for the past five years and more so at present, kept a job filing cabinet independent of the recent customer listing and job filing cabinet listed under selling. Into this cabinet goes literature pertaining to welding and applications of arc welding, new developments and new techniques in the welding field. Today, when the mechanics or welders read the trade magazines that we as a shop subscribe to, and find information that will be helpful in the future, the article is cut out and filed for future reference. It is impossible to remember all of this information, hence, when information is needed all the welders or foremen have to do is go to the job filing cabinet and pick out the information which is listed in alphabetical order under job headings. We continue to do research in all of our operating units and many new developments and applications are to be had by doing just this sort of thing. Progress is definitely a result of research.

Accounting—We have divided accounting into three parts which are: buying, pricing and records. Although buying and pricing are not directly connected with accounting except for listing or keeping tract of the account, they are listed here grouping them under "what books to keep and why". The buying for each operating unit is taken care of by the foreman of each unit or department as are the inventory controls. We keep a running stock record of each department which is checked daily and weekly. A sample inventory card is shown in Fig. 4.

In the welding department, whenever a welder or mechanic needs supplies, he makes out a "bin tag", (See Fig. 5). On this tag goes the material taken from the stock room, and the amount. When the welder returns material left over from doing a job he records the amount of material

Cost Record Card
______________Super Service

Job____________________Job No.______
Weldor_________________Date____19___

Item	Amount	Cost
Direct Material Steel plate Welding rods		
Direct Labor No. of hours doing job		
Hourly Overhead Cost (including indirect labor)		
Profit		
Total Cost		

Fig. 7. Sample cost record card.

returned on the same "bin tag" and totals the amounts taken and returned. These tags are checked daily and at the end of the week the total remaining supplies are listed on the weekly stock record sheet or inventory sheet.

When the welding foreman checks the "bin tags" and weekly stock record sheet, he can immediately see whether or not the supply is low, adequate or that we need to order supplies. He then makes out a "requisition", (See Fig. 6), which is handed into the office. The manager checks the material and either approves or rejects the requisition. If approved, a purchase order is made out and mailed. The purchase order and original or office copy of the requisition is filed and one copy of the requisition stays on the order spindle in the office and the other copy, (requisitions are made out in triplet form), goes back to the unit or department foreman so that he knows that the supplies have been ordered.

When the material is received, the foreman checks it for price, contents and weight. The foreman then returns his requisition to the office with his signature stating that the order of supplies has been received in good order

and that price and contents are correct. The account is then listed in the journal and ledger and also in the ledger of the welding department under ledger headings for that purpose. With the welding ledger, the welding foreman knows exactly what has been paid out for his department and at the end of every month welding sales are listed in the ledger, the ledger is balanced and the profit for the month made known and checked with the ledger in the office.

This inventory and buying system gives us an adequate stock at all times. We do not tend to overstock or understock but keep adequate supplies on hand at all times for our needs. If a requisition is checked for capital equipment, a conference is held between the foreman and manager or owner. Every piece of new equipment bought is discussed and checked with the "turn down slips" before the requisition is allowed to go through. As a result, we have practically no material or equipment that is not an asset to the department.

Pricing Work—The general opinion among proprietors of commercial welding shops and service stations that have welding as a unit, is that the general prices charged for welding are too low and there is too much price cutting. In setting up our hourly charge for welding and other work, we have grouped our overhead expense into one lump sum per year. This amount is then divided by 12 to arrive at the monthly overhead charge, and then by the number of hours or working hours in the month, to arrive at the hourly overhead charge for the shop as a whole. The overhead consists of all material and activity connected with the shop that is necessary to operate the business which includes assets fixed, current and miscellaneous, liabilities fixed, current reserves and net worth and revenue accounts plus direct labor, direct material and shop operating or production expense. The problem is to distribute this burden or expense so that each unit shall bear its own share. This is not easily accomplished with accuracy. We have made approximations which are sufficiently accurate for our use.

The divisions of our cost accounting or cost finding system are direct material, direct labor and shop expense. Our profit is somewhat arbitrarily fixed but is closely connected with the volume of business transacted. The profit on all jobs is based upon the selling price whatever it may be and this is based upon total cost.

We have found the daily overhead expense of operating the shop and this amount is then divided by six to determine the hourly overhead charge. Although we work eight hours per day, it is impossible to produce a full 8-hour work day because of time lost in changing from one job to another and short periods of inactivity waiting for the job to come into the shop. This hourly charged amount is in addition to direct labor, direct material and shop profit.

Pricing work in advance of doing the job is at best an intelligent guess. In order to arrive at a rather accurate price we use our customer listing and job filing cabinet constantly. A card, (See Fig. 2), has been made out for every type of job that we have done and some that we have not done, but have received from other shops. The cost information such as direct labor, direct material and shop expense are not listed on the "customer listing" and "job filing" cards because we are constantly showing these cards to customers for prices on jobs. A separate "job cost record card" is kept on which is listed the divisions of our cost system and the cost to us, (See Fig.7).

When a job comes into the shop and the price is requested by the

customer, the foreman goes to the job number sheet, finds a similar job number and goes through the customer listing and job filing cabinet and immediately has the price, material and labor that go into the job. If we make a mistake or incorrect charge on a welding job, we change the customer listing and job filing card to show the true cost of the job. This information is always available from the "cost record" cards.

If a job comes in for which we have no "cost card" and "customer listing" and "job filing" card, and the customer wants an exact price, the foreman measures the length of the welds to be made, estimates the material to be used and secures its weight, if steel from our steel suppliers catalog He then estimates the amount of welding electrodes to be used by referring to "The Procedure Handbook of Arc Welding Design and Practice" under the section on "Procedures, Speeds and Costs". The amount of labor necessary to do the job is estimated from past experience, the current to be used in welding and the overhead charge per hour is added. This information is then totaled on a "shop tag", (See Fig. 8), and the shop profit is added to give the selling price of the job. Accurate information on all items of cost is absolutely necessary in order to make the correct charge. With this method, we have made very few mistakes and have had very few jobs that do not show a profit, and we can depend upon the foreman to know the items of cost going into the job.

When the price has been given the job is tagged with a "shop tag",

Job Tag

Name__________ Date____ 19__

Material Used	Amount	Cost
Welding Rod		
Steel		
Flux		
Oxygen		
Acetylene		
Preheating Fuel		
Gasoline		
Labor Charge		
Electricity		
Remarks:		
Total Charge for job		

Fig. 8. Sample shop job tag card.

(See Fig. 8), and the necessary information is listed when the job is finished. The welding foreman or welder takes the tag to the office where a sales slip is made out. When the customer pays for the job, the sales slip is marked paid and if a question is raised about the price of the job, the "job tag" is there to give the necessary information. If the individual is a new customer, his name and job is listed in the "customer listing and job filing" cabinet, and the job is given a job number or if the job is new to us the job is given a new job number and the job and number are listed on the "job number sheet". A cost record is made out on the job and the profit is determined. The account is listed in the "daily journal" and in the ledger or book of subsequent entry.

Records (What Books to Keep and Why)—The main purpose of any business is to make a profit for the proprietor, and the record to determine this profit is bookkeeping or accounting. Since accounting follows a rather set pattern of rules, the make-up of the books and their development of the account will not be discussed. The accounting system is designed to express the actual condition of the business and changes that take place in the owner's or proprietor's interest. Since welding is a unit of the shop, the discussion here will be on the records or books used in connection with welding as it fits into the service station accounting system. The main source of information on business conditions of the shop is revealed by the "main journal" or "journal of original entry". Into this journal goes the explanation of the account under the account titles for each entry. Since accounting is the process of recording the financial history of the service station, a great deal of care must be exercised for sufficient explanation of each account so that its full history can be understood. Fig. 9 is a sample journal of original entry sheet and illustrates the point.

Just recently we have found it necessary to open a cash book in addition to the journal of original entry and ledgers. This has been necessary because of increased business activity and because we were beginning to have difficulty in securing this information from the journal because of the time involved. The cash book gives us information on all transactions that increase or decrease the supply of cash on hand.

Since it is almost impossible to pick out from the "journal of original entry" all the transactions that affect one phase of the business, it becomes necessary to group accounts as a classified record of the total changes in accounts. These requirements are met in the ledger, (standard), which is identified as the "book of subsequent entry". A separate page is given each account in the ledger, and all pages are identical and are identified with the same number as in the folio column in the journal, (See Fig. 9), under ledger reference. The accounts in the standard ledger are listed under the headings of debits and credits. The method of balancing the accounts consists of adding up the debits and credits, determining the difference between them and adding this amount to the smaller side to balance. The credits and debits are then listed under their respective headings on the "trial balance sheet" which is prepared monthly, added up and the total debit balance must equal the total credit balances. This is nothing more than proving the accuracy of the accounting records.

The cash book is balanced and checked daily while the ledger and journal are balanced monthly. At the close of each month, the bills of the shop are taken care of, and monthly statements are sent out.

Our accounting system is our most valuable aid in completely analyzing the financial structure of our service station. Although routine is of the

December 1941	Ledger Reference	Debits	Credits
2			
Purchases Merchandise	3	$6.00	
Cash	2		$6.00
From ______________ Company	1		
50# No. 5 Welding Electrodes			
3			
Purchase Merchandise	3	$255.00	
Cash	2		$255.00
From ______________ Company	1		
250 Amp. A.C. Welder			
8			
Sales Merchandise	8	$45.00	
Mr. ______________	7		$45.00
Auto parts sold to him on terms 12/4/41			
12			
______________ Welding Supply Company	4	$300.00	
Cash	2		$294.00
Net Worth	9		$ 6.00
For payment of invoices on December 6, less 2%			
13			
Merchandise Salses	8	$3.00	
Mr. ______________	5		$3.00
Welding job and material 12/12/41			
30			
Net Worth	9	$100.00	
Cash	2		$100.00
For payment of wages to date			
		$709.00	$709.00

Fig. 9. Sample journal of original entry sheet.

utmost importance, there is no substitute for it and it does not become a burden when one realizes that the accounting must be kept up and that it is the "governor" of the business. We are going through a considerable business enlargement which will necessitate change in our accounting system. However the underlying principles are the same for a small or large busi-

ness, hence our accounting system will be just enlarged from what we now have.

Personnel—Our personnel department consists of a filing cabinet for employment application blanks, qualifications for the operating units, wages, advancement levels, positive outline of job limits and shop placement of employees in operating units or jobs for which they are best fitted. We have changed our employment application blanks during the past two years to give us information governing the prospective employee's place in civilian life, (See employment application blank, Fig. 10). We are interested in our employee's background from all angles so that we are reasonably sure that if employed by us, the employee will adequately handle the work and be an asset to the shop.

When a person applies for a job in the garage whether personally or by letter we give or send him an application blank. When the blank is returned, we contact his former employer and other references for additional information on his work and social life. When this material comes in, we file it with

Last Name First Name Middle Name Where do you live now?
Farm or place under
Home Address Telephone No. 2500______
Home address if different from local______ Place of 2500 or more

Name and address of employment service registered Race and sex, marital
with______ male Female status
City County State ____White____Single
Age last Birthday ______ ____Negro____Married
Date of birth______ ____other____
Nationality of father______Mother______
Social Social Security No.______Have you a copy of your
birth certificate______Draft calssification______
If of foreign birth, answer the following: How long have you lived in
the United States______Years. Are you a naturalized citizen?
______If naturalized, what is your certificate number?______
What court issued your certificate?______
Give date on which issued______Give name of court______

Educational Record

In elementary and secondary school 1, 2 3 4 5 6 7 8 9 10 11 12

Have you attended a trade or vocational school?______
If so give the anme of the school______
Number of months attended school______
Name of vocation for which trained______
Date left______Did you take chemistry pretaining to materials?
______If not did you take any chemistry?______kind______
Did you take physics?______Shop Mathematics?______
Bookkeeping?______What line of work are you interested in?______

Would you consent to having us place you in a different line of work if
we see fit to do so?______

Employment Record
If now employed give details below on your work______

By whom employeed______ Address______
Length of time employed ______Kind of employment______

Wages?______Per______Give the names of two additional
references, prefe.able on educational reference______

Additional information and employment may be written on the other side
of this sheet.

Fig. 10. Sample employment application blank.

the application blank and if favorable, we contact the prospective employee. We find it essentially necessary to learn everything about our employees possible that will assist us in placing them in the right job, and to bring to a minimum misplacement of men who do not fit and avoid hiring people whose background of training is good but whose work habits are not the best for employment. We are interested only in information concerning the employee's work and work habits. All other information is strictly the employee's own personal business and does not concern us.

If the applicant is hired, he is put to work in his own field if experienced, and if not, he is put to work wherever help is needed and allowed to select the unit or field of work in which he is interested. Employees with no past experience receive $16 per week for the first three months, $18 per week for the second three months and then $20 per week until the employee warrants a raise. Men with experience receive $25 per week for the first month and from there the mechanic is paid above $25 on the basis of productivity. This information is gained from the sales slips.

We prefer people with a high school education or with vocational school training. Although this is not a requirement, it is highly desirable and we select our employees with this background over those without it. All foremen must have a high school education or vocational school training and three years' trade experience as a minimum. Their salary ranges from $30 to $38 per week.

We have found that many men fail because of not having the opportunity to advance. In order to allow advancement we have set up positive outlines of job limits. At any time an employee has the privilege of going to the manager and stating his case for advancement, and if good he is given time to prove that he can produce and show a profit. If he is successful, he is advanced to assist the foreman and to take over for him when absent. In addition he is given a $3 weekly raise. The information on the mechanic's ability to produce is gained from observing the employee, the sales slips and unit ledgers. Two of our employees have advanced to become assistant foreman during the past two years and have done an excellent job. We do not wish to hold anyone down and by allowing this advancement the unit foreman is always on guard to see that he knows his job.

Applicants for welding must have a high school education or have completed courses in chemistry pertaining to materials, physics and shop mathematics. The prospective employee must show interest in welding and this is brought out during the interview. Very often we place our employees in other units of work so that they may be able to assist in these units when work in their major unit is slow, or when we experience or have a rush period of work in other units.

Many men are able and qualified to handle bigger jobs than they now hold. We endeavor at all times to give our men the opportunity to take over a job about which they are doubtful in order to show them that they are capable of a more responsible job. This is allowed after they have discussed the procedure with the foreman. The main purposes of the shop personnel department are to place the right man in the right job, pay the right wages and provide opportunities for advancement.

Conclusion—In this analysis, we have given the organization of the service station and its advancement or progress during the past two years. There remains much to be done and we have endeavored to point out the operating units and the necessary activity to operate the business. We feel that welding has been launched as a new tool for progress.

Chapter III—Straight Line Mass Production Methods Speed the Defense Program

By George F. Wolfe,

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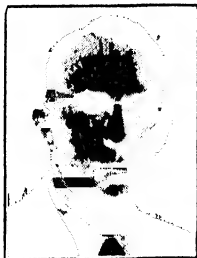
George F. Wolfe

Subject Matter: Assembly line method used for the production of submarine chasers and other vessels. Large sections of the hulls are prefabricated by welding. The partly completed vessels are then assembled side by side in a line. The vessel in the launching ways is launched sideways and the vessel next in line is moved into its place by transfer carriages. Throughout the plant every effort is made to secure positional welding. Jigs are used for the assembly of sections. In applying stiffening members to plating a traveling head moves over a loose assembly and holds members in place for welding. Large bending machines are used to bend plates to various angles. A reduction in welding time and improvement of weld is noted. Savings have been definitely established.

Foreword—The definition of a "Plant Weldery" as that part of a plant supplying welded parts for the rest of the plant must be given a rather wide interpretation. A few years ago "Plant Welderies" were small departments tucked away in some obscure corner so they would not interfere with the main operations of the average industry. This is no longer the case as the phenomenal advancement of welding has burst these bonds of restraint and today we have gone all out for welding and have developed what may properly be termed "Welding Plants".

This is not a paper on shipbuilding. It deals with an original and unique method of manufacturing which can be used to cover a wide range of welded products and its use is peculiarly adapted only to welding. The description of ships and shipbuilding included herein constitutes only one possible application of this method.
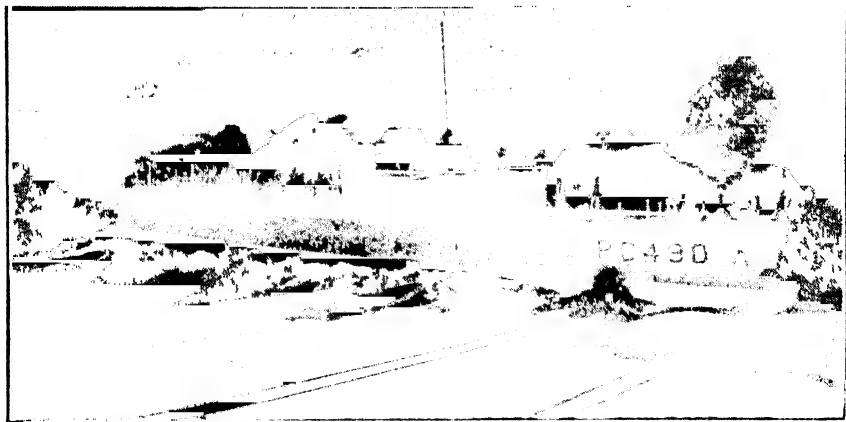
Fig. 1. Submarine Chaser PC-490 was the first all welded sea-going fighting vessel to be launched from a production assembly line.
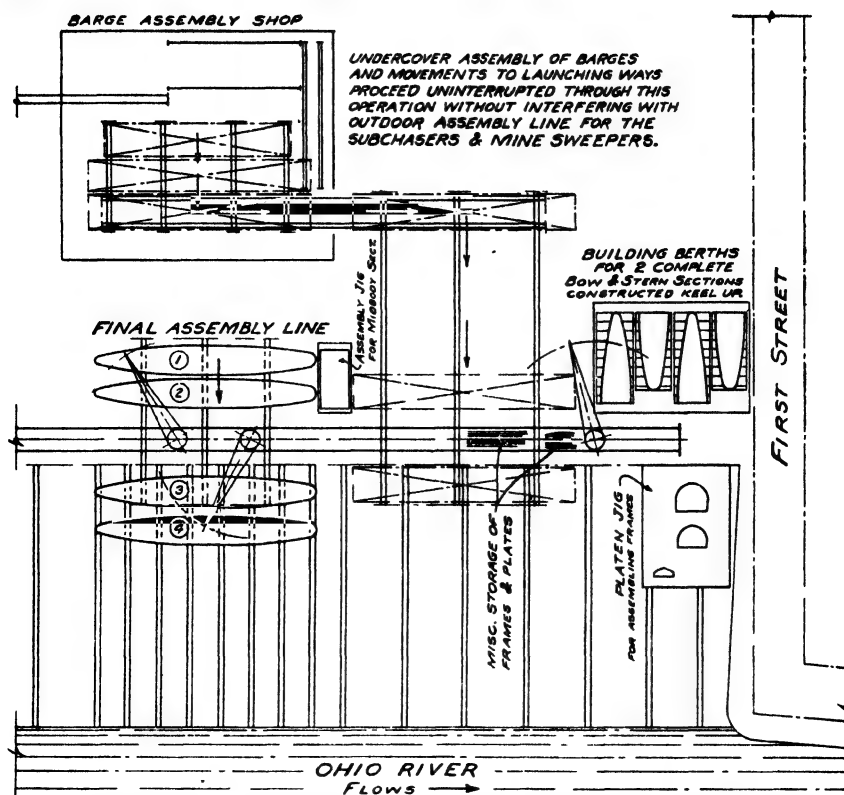
Fig. 2. Final erection of subchasers on new outdoor assembly line permitted maximum production proportionate to launching way space required.

Straight Line Mass Production Methods Speed the Defense Program—Shortly after noon on October 18, 1941, amid the applause of thousands of spectators and the whistled salutes of river craft, submarine chaser PC-490 slid smoothly from the launching ways, (See Fig. 1), and floated gracefully on the placid surface of the Ohio River. For the first time since the War of 1812 a sea-going Navy fighting vessel had been launched at an inland river shipyard.

That was the making of history from the angle of the news reporter, but more important to industry, and to the welding industry in particular, are the developments which preceded this launching and which have permitted the launching of subsequent vessels from the same ways at unusually frequent intervals ever since as part of a program which can continue as long as the present national crisis demands.

Long before the troubled murmurings of a world in turmoil reached the upper waters of the Ohio River the operators of this shipyard had recognized the inevitable growth of welding and had done considerable about it. In the so called old days, and at that only ten years ago, this was a plant almost entirely given over to riveting. At that time no attempt was made by the operating force to develop riveting guns as the market was well supplied by the manufacturers of such equipment. Likewise with the swing over to welding, it was felt that there would be an ample source of supply for weld-

ing equipment. Thus the efforts of the operating personnel were left free to concentrate on the thing that was felt to be of even greater importance than the equipment itself: the development of methods to utilize this new tool for the greatest benefit of all concerned.

The PC-490 was the first Navy fighting vessel ever to be launched from an assembly line. The application of assembly line methods had been instituted in an indoor assembly plant at this same shipyard in 1937 to insure the year around uninterrupted production of river equipment. With the sudden demand for an immense increase in ship production and the rapid congestion in the established shipyards, attention was focused upon this plant to see if the assembly line method of production could be expanded to meet the emergency. After a thorough investigation by the Navy Department, contracts covering various types of vessels were awarded this plant and production assembly lines for the building and launching of a great number of vessels have been placed in service at three yards located at Pittsburgh, Pa., Wilmington, Del. and Stockton, Cal.

With the introduction of Navy vessels into an inland shipyard there was also introduced the problem of continued production of river craft of almost equal importance to meet the demand for the transporation of oil, coal and other materials needed in connection with the same defense program. The launching ways at the Neville Island Plant in the Pittsburgh district are of the side launching type with the total length of available ways definitely restricted due to property limits and existing structures. The usual type of river craft is of a fairly simple structure and can be assembled in a few weeks, but the Navy vessels, being of a much more complex structure, usually require several months in the erection berth before they are ready to launch.

Fig. 3. The transfer carriages, equipped with hydraulic jacks, permit the movement of any size vessel on the production assembly line.
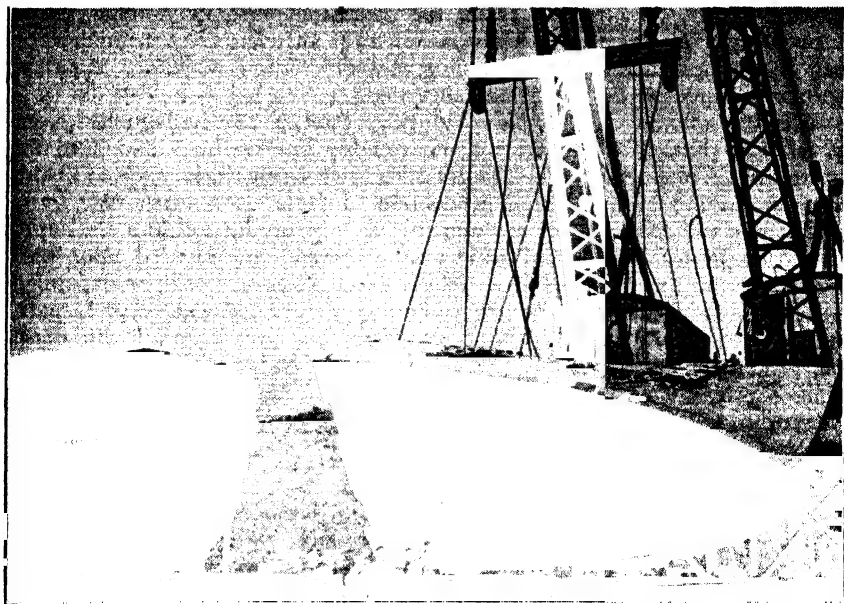
Fig. 4. The combination of two whirler cranes with fairly simple rigging permitted the turning over of large irregular preassemblies.

Reference to the sketch shown in Fig. 2 will show the location of the assembly line that was built in the summer of 1941 at Neville Island as a solution to this first problem of additional way space without the sacrifice of too much of the productive area. Three lines of transfer tracks were built between the existing indoor assembly plant and the sloping launching ways. As you will note from the sketch, this space permits the location of four vessels in line while the transfer track system provided for the movement of the vessels progressively forward from position No. 1 to position No. 4 from which they are launched.

The movement of the vessels in their various stages of completion is accomplished by means of a number of four wheel carriages equipped with hydraulic jacks, (See Fig. 3). These carriages, of 120 tons capacity each, have the jacks built in at each corner and are operated by a hand pump which controls all four jacks. The pressure system is supplied with a gauge which is used to equalize the load on the several carriages so that the ship will not be subjected to undue strains. The wheels, which are roller bearing equipped, are of solid steel 18 inches in diameter by 4½-inches thick and run on tracks consisting of a six inch channel with flanges upwelded to the top flange of 24 inch I-beams resting on concrete piers. At the point of cross-over with the whirler crane track removable sections are used for the transfer tracks to provide for unobstructed crane operation except at the time of transfer of the vessel across the crane track.

The space provided by this new assembly line was not sufficient in itself to make full provision to meet the requirements of the delivery schedule set up. Before any erection was started in position No. 1 the entire hull of these vessels, with the exception of that section comprising the engine room, was erected in an upside down position elsewhere in the yard in the location shown in Fig. 2. Structural steel jigs, resting on concrete foundations, were

provided for this preliminary assembly. These jigs were of a fairly simple nature due to the inverted position of the ship as it was only necessary for them to conform to the almost flat deck surface.

The preassembly area described above was in turn likewise provided with subassemblies built up elsewhere. A platen located near the upside down assembly site served for the assembly of all frames before their entry into the larger units. All bulkheads were assembled on flat steel floors located in the main structural shop before being brought to the erection site. Since it is not the purpose of this paper to enter into a discussion of welding technique we will not go into the details of the welding of these bulkheads except sufficiently to point out the need of proper equipment for work of this nature.

The bulkheads entering into these vessels were of light gauge plate with tee stiffeners at frequent intervals. The result of the combination of considerable welding with light steel was unusual distortion which had to be kept out or removed later with great expense and delay. After many experiments the method adopted was to first weld the joints of the individual plates and then tack the entire plate assembly securely to a flat steel floor before the addition of the stiffeners. A half inch bow was put in the stiffeners so that when they were forced down to the plate and tacked, the contact edges were in compression, thus offsetting the normal bowing from the subsequent welding. Welding of the stiffeners was then completed and the few resultant buckles were removed by the spot heat and water quench method.

Since the main hull sections were built in jigs in an upside down position, their transportation to the erection site in position No. 1 on the assembly line and the turning over of these sections had to be given careful study. The transportation problem was easily solved as several gantry cranes were available so the turning over of these large irregular pieces became the major problem. As the general cross section of the hull, and particularly that of the bow section, approached a triangle, the center of gravity lay quite outside the center of rotation as the section would be rotated, so that critical

Fig. 5. Production line methods utilize large areas for erection quite remote from the actual launching ways where space is at a premium.
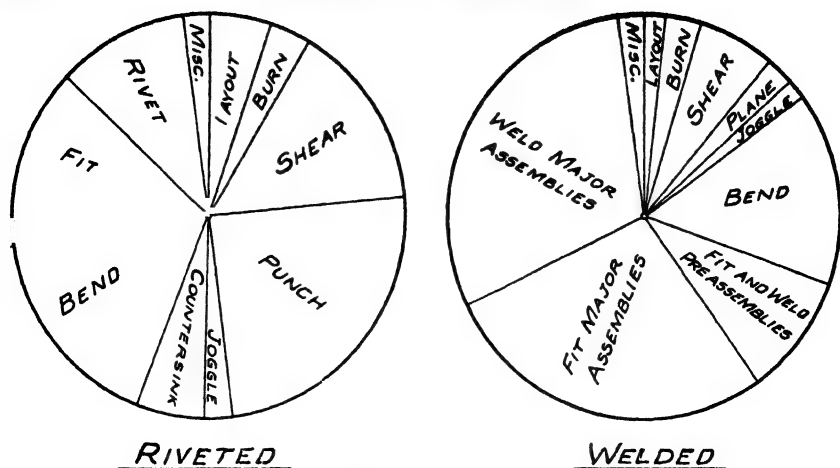
Fig. 6. These graphs show a comparison of the cost of the various operations in the shop fabrication of steel for a coal barge. In the case of the welded barge, fitting and welding, totalling almost 70 per cent of the work require large floor areas but reduce final erection time and expense.

positions would be encountered in the turning operation. Model tests were made to determine these critical points and it was decided that the turning operation should be accomplished with block and tackle in order that hauling and snubbing would be coordinated.

References to the photograph in Fig. 4 will show this turning rig which consisted of an equalizing beam fitted with shackles and a pair of 30-inch diameter sheaves. One inch diameter wire rope slings were fitted around the hull sections and passed over the sheaves. A belt of wooden planks, three frame spaces wide, held together by means of a 3/8-inch diameter wire rope strung through them, then tightened around the hull section by means of a turnbuckle, was placed between the slings and the hull for protection. A gunwale protecting timber was also fitted in way of the turning cables and the hull was shored internally to prevent squeezing.

A preassembly was lifted and brought to the erection site, and, while the main hooks of two gantry cranes held it in the air, the turning was accomplished by the block and tackle, one end of the line being secured to a lug welded to the hull. As a measure of precaution, and in order to overcome the tendency of the preassembly to roll back at the critical positions, another turning line was connected to the whip hook of one of the cranes. Similarly snubbing was done through a block and tackle and again a separate snubbing line was attached to the whip hook of the second crane. Through this method of rigging the turning of the preassembled hull sections was kept under control at all times.

Upon completion of the turning operations of the forward and after sections they were set in place on permanent steel blocking carried on concrete foundations. The engine room section was already in place so the end sections, while still held by the main hooks of the two gantry cranes, were pulled home by means of turnbuckles attached to lugs welded to the adjoining sections. At each joint about 18 inches of the lap of the shell plates had been left unwelded to facilitate fitting and to assist in controlling the over-all length of the vessel at this time.

Following the assembly of the first hull in position No. 1 and the finish-

ing of enough welding to permit its movement without fear of distortion, the transfer carriages were placed in position and the entire assembly was picked up and moved over to position No. 2. As additional hulls were erected the movement was progressively forward and when the line was entirely filled the first hull was ready for launching with all the exterior under water work completed and all of the heavy machinery in place.

Many benefits were shown in the application of the use of assembly line methods in the building of these submarine chasers among which are the following: (1) a substantial reduction in fitting and welding time; (2) an overall improvement in the quality of the weld in direct ratio to the amount of position welding obtainable; (3) building the vessel in sections allows relief points for locked up or internal stresses due to welding shrinkage and permits adjustment of proper overall length of the vessel; (4) the possibility of using a greater number of welders with only average qualifications, that is, qualified for downhand welding only; (5) conservation of launching way space.

We have cited here only one specific case of assembly production line methods with a few of the benefits which are the direct result of these newer methods of construction. Before pursuing this subject further we wish to divert your attention away from the assembly yard long enough to portray some of the very important changes that are necessary in the fabricating shop in order to meet the demands made by the assembly lines for proper preassemblies. Once the matter of shop fabrication is disposed of we will discuss other assembly lines which are now in operation as well as some now under consideration which are a most radical departure from any hitherto considered.
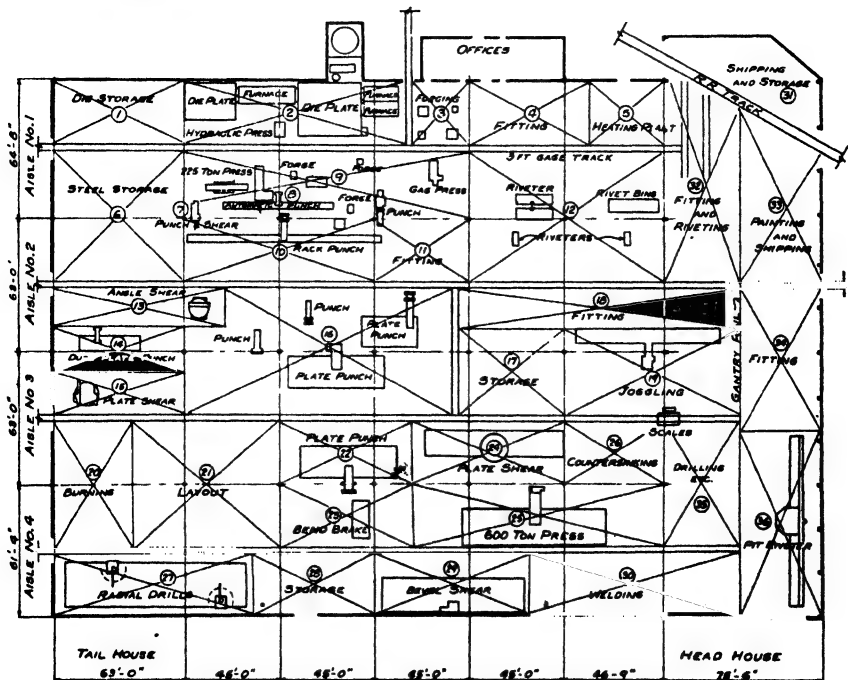
Fig. 7. Detail layout of original shop for riveted work.

Fig. 8. Structural shop designed and rearranged to meet the demand for large shop assemblies dictated by welding.

Fabricating Shop Requires Modernization to Meet Demands of Assembly Production Lines—The introduction of welding into a structural shop built up for riveting raised many new problems and the advent of assembly lines for ship erection intensified the situation. This shop, in common with many others, was a well arranged shop for riveting and had reached a peak of production in 1929. At that time a total tonnage averaging about 2500 tons per month was fabricated, mostly riveted and largely barge steel.

Shop operations were confined to what we may term fairly simple operations: shearing, burning, a limited amount of bending, punching and riveting. Very few shop assemblies were made in ship construction except for some flat work which was limited to bulkheads, trusses and rake frames. In many fabricating shops similar to our own, economical design was handicapped due to the lack of proper equipment and particularly such machines as bending rolls and press brakes. In barge construction, as well as in seagoing vessels, corner angles were used in place of bent plates with the resultant loss of cargo carrying capacity.

As welding became more common and new plants were placed in operation with little more than burning and welding equipment, shop assembly was not introduced at first and most of the welding was done at the erection site. The product of such plants was usually of the tailor made type and these plants did not lend themselves to speedy or mass production. With the increase in business starting in 1936 the first demand for all welded equipment arose as welding had been growing during the depression. This demand, coupled with the fact that positioned shop welding was of better quality and more economical than vertical and overhead welding at the erection sites, soon dictated better shop equipment for mass production.

This influx of welding and its requirement for shop assemblies of a type hitherto unheard of created new fabricating requirements, the main one being sufficient working area. Reference to the circular graphs in Fig. 6 illustrates this need. In a riveted barge approximately 75 per cent of the shop labor and required area were taken up by the preparation of the steel prior to fitting. This material was mostly flat work easily stacked and not requiring much working area. Since most of the steel was shipped to the
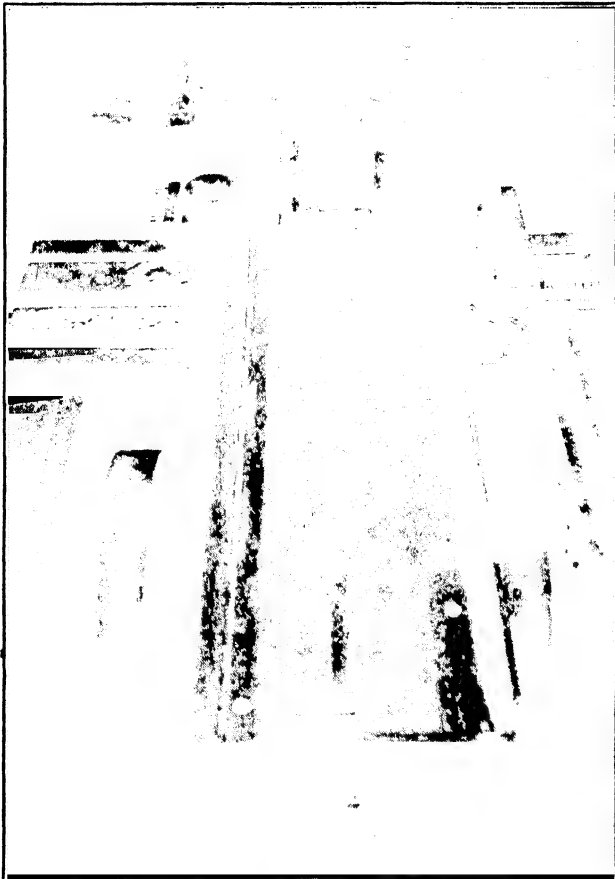
Fig. 9. Shapes properly proportioned for welding are cut from standard channels in special die equipped punch.
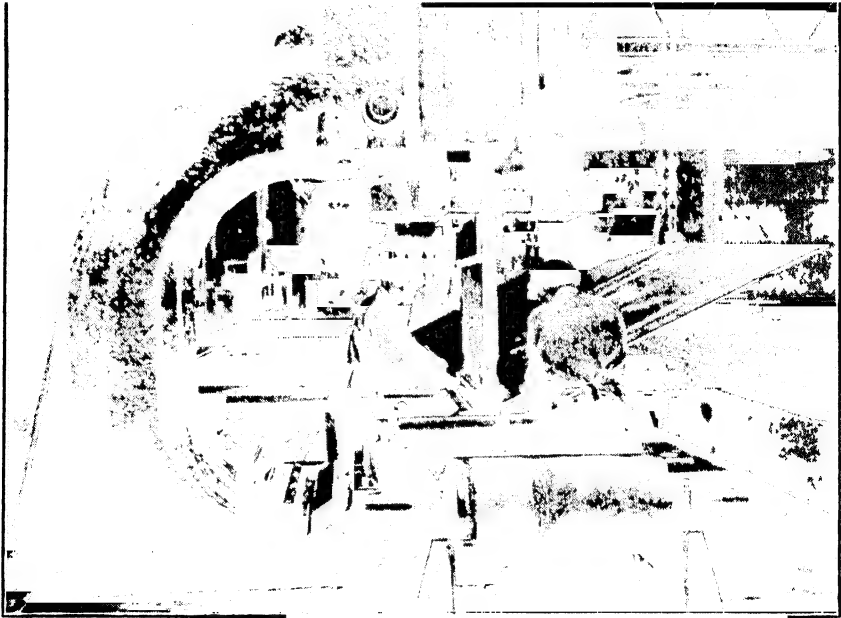
Fig. 10. This 600-ton punch press, equipped with a variety of dies, can produce practically every type of bent plate fabrication required.

erection site without shop assembly the area devoted to fitting and riveting was small. For the welded barge these conditions were reversed as fitting and welding were now the major operations. The shop assemblies are of a vastly different nature requiring much space and special equipment such as steel assembly floors, surface tables and numerous jigs.

A typical shop of the riveted era is shown in Fig. 7 with its machinery spread over the entire shop and having only small scattered areas for the fitting and riveting requirements. With a total change in space requirements as shown in the graphs in Fig. 6 this shop had to be rearranged in order to get proper and economical productivity.

The results of this rearrangement are shown in Fig. 8. An extension was built at the lower right corner of the shop and all fixed fabricating machinery was moved to the left end of the shop toward the source of incoming material. Of an area approximately 120,000 square feet in the entire shop, more than 70,000 square feet or about 60 per cent of the under roof area was now available for large shop assemblies, never dreamed of in the days of riveting but absolutely essential to the success of the application of production assembly line methods to shipbuilding.

As the rearrangement of the shop progressed much of the punching and riveting equipment was scrapped or altered to suit present day requirements. A rack punch, originally installed for the multiple punching of shapes, has been fitted with special shear blades for the purpose of shearing standard channel sections on a serrated line as shown in Fig. 9. The resulting two pieces, produced at a minimum of expense, have the general shape of an angle but a depth two thirds that of the original channel provides a most efficient distribution of the material. This new section, made possible by providing special shop equipment for its manufacture, permits sealed welding with the equivalent of only 50 per cent of a single full continuous bead.

Originated at this plant, the serrated angle construction has been adopted by the navy department and is being used in many vessels built for the defense program.

The studied application of welding has shown the economy of keeping the amount of welding to a minimum and has directed attention to the benefit of using bent plates in lieu of welded corners. While this is true in structural work generally an even greater saving is found in barge and ship construction. Most vessels require a right angle plate bend at the junction of the deck plating with the side plating and a bend of considerable radius at the bilge line. The punch press shown in Fig. 10, with a short length of die, was capable of performing such operations but required a great number of strokes to bend such plates which usually run from 25 to 35 feet in length with the bending on the long side of the plate.

In order to meet the requirements for the bending of such plating more economically an unprecedented size of press brake was built to our specifications. The five-foot gap on the former press was incorporated in the new press brake, shown in Fig. 11, but the length of die was increased to 36 feet and enough power was supplied to bend plates up to ¾-inch in thickness and the full length of the die at a single stroke. Today this is one of the busiest and most useful tools in the shop. In addition to taking care of all plate bending operations for our own activities we have contracted to bend plates for other shipyards and during the past year we have bent more than 25,000 tons of plates up to 36 feet in length for use by eastern coast shipbuilders.

The development of the use of production assembly lines for the erection of ships at the launching sites set up shop requirements not previously de-
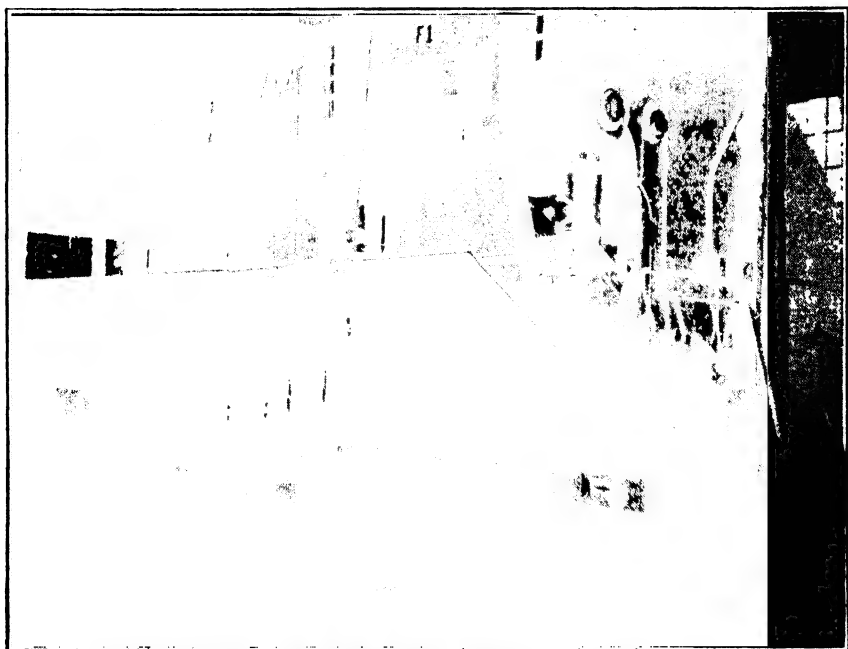
Fig. 11. This newer type of press brake has a capacity of bending a 36-foot by ¾-inch plate to 90 degrees or more in a single stroke.
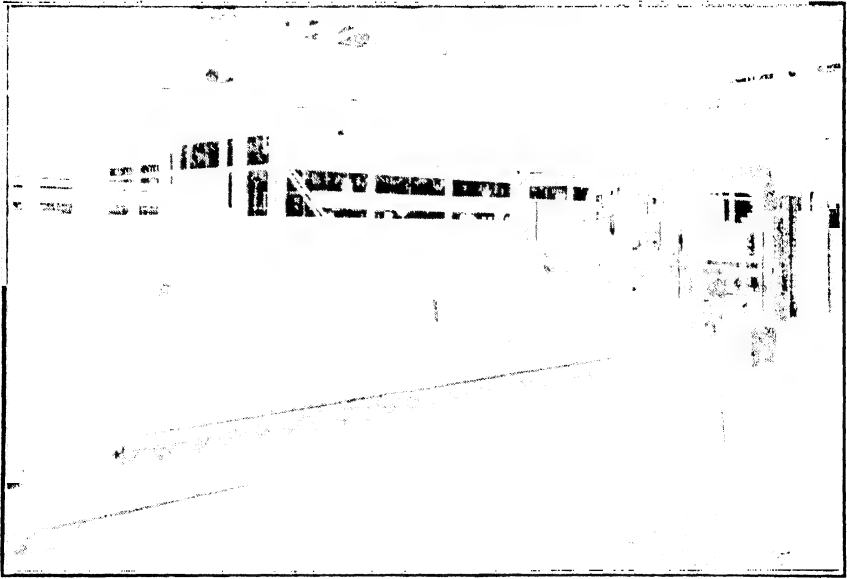
Fig. 12. The design of this "fit and tack" machine permits the rapid placing of materials in it by the overhead traveling crane.

manded. In order to keep the assembly lines in motion it is necessary to deliver to them as large preassemblies as can be handled to the yard. The final results in the yard are greatly dependent upon the accuracy of such preassembled sections so provision must be made in the shop for true and accurate assemblies.

One of the primary shop assemblies is the application of stiffening members to plating. As a hand operation this process is slow and expensive, requiring careful layout work on the plating and the tedious fitting of the stiffening members, which usually consist of an angle with a toe contacting the plate. Proper consideration of this problem resulted in the design and development of the "fit and tack" machine shown in Fig. 12. This machine consists of a steel floor over which is mounted a traveling head. In operating this machine a plate is laid on the steel floor in a position determined by jigs and the longitudinal stiffening members are dropped into jigged slots for approximate location. The fitting head, shown in Fig. 13, which is equipped with horizontal adjusting and vertical clamping motions, is then run over the assembly and holds the longitudinals firmly and accurately to the plate for hand tacking. The traveling head, which works in either direction of movement, is run off in the clear at either end of the floor so that overhead cranes can handle the materials to the machine and remove the assemblies quickly and economically.

Jigging of assembly operations is utilized wherever possible. A recent visitor referred to the "fit and tack" machine as the most expensive jig he had ever seen, but the results have justified the investment. Numerous other jigs are used from the simple type of flat plate jig for such items as rake or transverse frames up to the elaborate box type of jig shown in Fig. 14, where a side box section of a coal barge is being assembled. The box section shown, having dimensions of 35 feet by 11 feet by 3 feet, is one of four such sections comprising the entire side of a 175-foot coal barge

and is largely dependent on proper jigging to insure that accuracy of shape and dimension necessary for the successful usage of large preassemblies.

Even larger jigs are required at times and for this purpose large plane steel floors are provided as a base for such jigs. The use of such a floor for jigging is shown in Fig. 15, where a 45-foot towboat is being erected upside down on a jig built up from the steel floor to fit the irregular deck of the vessel. Similar jigs have been used in outdoor assembly such as referred to in the preassembly of subchaser hulls and in the building of large towboats. Fig. 16 shows the erection of the entire forward section of a towboat having a beam of 36 feet. Similar jigs were used for the very irregular aft hull sections of this twin screw, tunnel type towboat and it is needless to point out the economy of such a procedure and particularly so where half a dozen vessels were built.

Throughout the shop preassemblies every effort is made to get positioned welding. We previously pointed out some of the advantages of positioned welding such as the ability to use more ordinary welders. The value of positioned welding cannot be overestimated so every effort is made to place the work in the proper position for downhand welding. For flat work such as the plate and angle assemblies coming from the "fit and tack" machine, tilting tables such as shown in Fig. 17 are used. In the case of the larger assemblies which are often carried into sizes such as shown in Fig. 18, where rake ends 30 feet by 12 feet by 9 feet are shop assembled, other methods are used. These larger assemblies are turned into various positions by the overhead cranes and inclined beams are provided at the side walls of the shop to support these large sections at the proper angle for most efficient welding as shown in Fig. 19.

Hand welding has played the major part in shop welding in the ship and structural shops to date. In this plant a training school is operated constantly in order to furnish properly trained men. The standards are high as practically all of the work is under the direction of various govern-
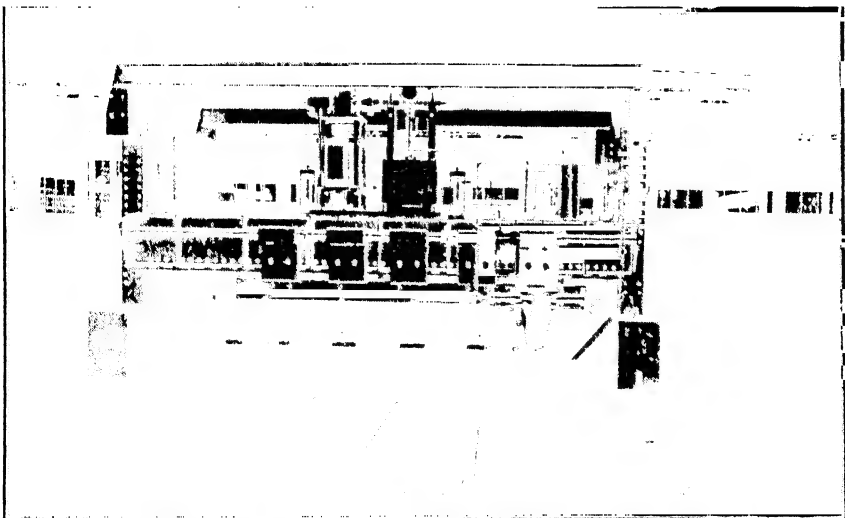
Fig. 13. The traveling head moves over the loose assembly and then holds the members firmly and accurately in place for hand tacking.
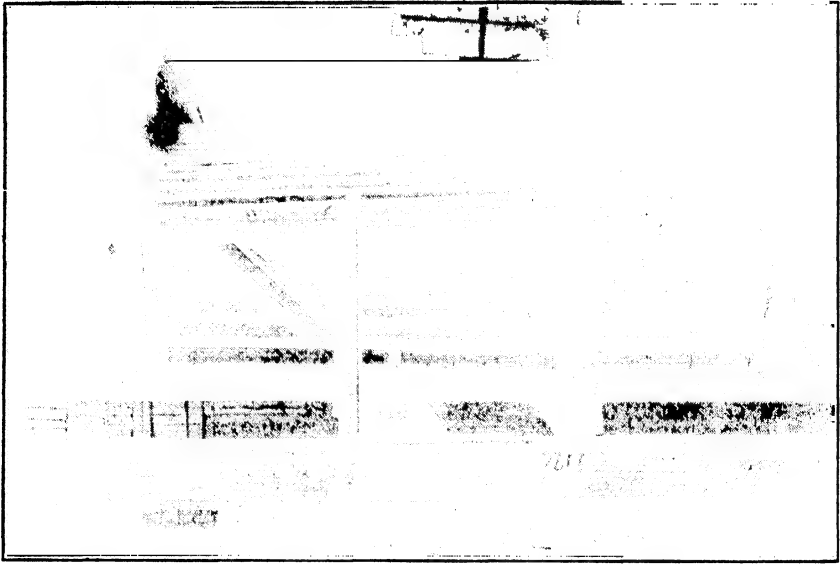
Fig. 14. This sizeable jig provides for the speedy and accurate assembly of a coal barge side box section measuring 35 by 11 by 3 feet.

ment inspection or falls under the classification of the American Bureau of Shipping. At the Wilmington yard, which is quite removed from the Neville Island plant, many of the welders come from the local trade schools and with some additional training develop rapidly into good welders

The application of automatic or machine welding has been studied for many years and is gradually being developed. The large assemblies built up in a shop of this nature do not lend themselves to ready handling to the welding machine so it was necessary to devise means of taking the machine to the assemblies. A Tornado welding unit was mounted on a wall crane as shown in Fig. 20 in such a manner as to cover a floor area of approximately 25 feet by 200 feet. With such a large area available it is now possible to place enough work under the machine to secure continuous and economical operation. To secure the best results, care in design of the structure to be welded in a machine operation is very necessary so that long continuous welds are in accessible locations. One of the most successful applications of the carbon arc has been in the welding of side box sections for carfloats. These preassemblies, as shown in Fig. 21, are about 24 feet by 11 feet by 9 feet and weigh 18 tons each. Proper design for machine welding provided a large number of full length welds on these box sections. Thus in one lot of fourteen carfloats approximately ten miles of automatic welding was obtainable by means of a judicious combination of designing for the welding operation and providing a flexible mounting for the welding equipment.

All of the changes in shop arrangement and the introduction of new equipment have resulted in many economies and have permitted an increase in production which was most timely. This shop, with a maximum production of 2500 tons per month on riveted work has more than doubled this performance on welded fabrication since its modernization. Further this welded fabrication has been carried to a much more advanced state of completion in the shop than was the former riveted output. This greatly

increased efficiency is the direct result of coordinating a well developed welding organization with a properly equipped shop.

The Development of Production Assembly Lines in Shipyards—The first attempt to adapt the principle of production assembly line methods to ship construction was made at the Neville Island plant of Dravo Corporation in 1936. Vessels were erected in positions inboard of the crane tracks and were moved over into the launching position on concrete filled pipe rollers. This was an experimental step and the advantages were so apparent that plans were placed underway after a short trial period which resulted in the building of the first indoor barge assembly plant.

This indoor plant, which is shown in the upper left hand corner in Fig. 2 was successful from the beginning and soon demonstrated the many advantages of applying production methods to ship construction. With the advent of increased production necessitated by the defense program and the requirement for rapid expansion of shipbuilding facilities, additional assembly lines appeared to be the proper answer.

The first requirement was the building of a number of Navy vessels and assembly lines were set up for this purpose at yards in Wilmington, Del. and Stockton, Calif. Remarkable speed was obtained on these lines and the deliveries of the vessels were most satisfactory. Some of these vessels were sublet to an established west coast builder but Dravo was able to build an entirely new yard incorporating an assembly line and complete a larger quota in less time than the subcontractor required using conventional methods.

A second project soon followed the first navy order and a general survey of yard requirements indicated that additional lines would have to be added

Fig. 15. Large plane steel floor areas facilitate the jigging of such irregular shapes as the all welded 45-foot towboat hull shown here.

at both the Neville Island and Wilmington yards if private contracts were to be completed together with the rapidly growing demand for Navy equipment. The schedule of deliveries for the vessels discussed previously required a minimum of four building berths which, as will be noted by reference to Fig. 22, would have required half of the entire building area available on the launching ways.

With the barge shop already in service it was considered most desirable to keep the flow of vessels from it quite uninterrupted so a new assembly line as shown in Fig. 2 was erected. This new line permitted the securing of the requisite number of building berths at a minimum of expense and
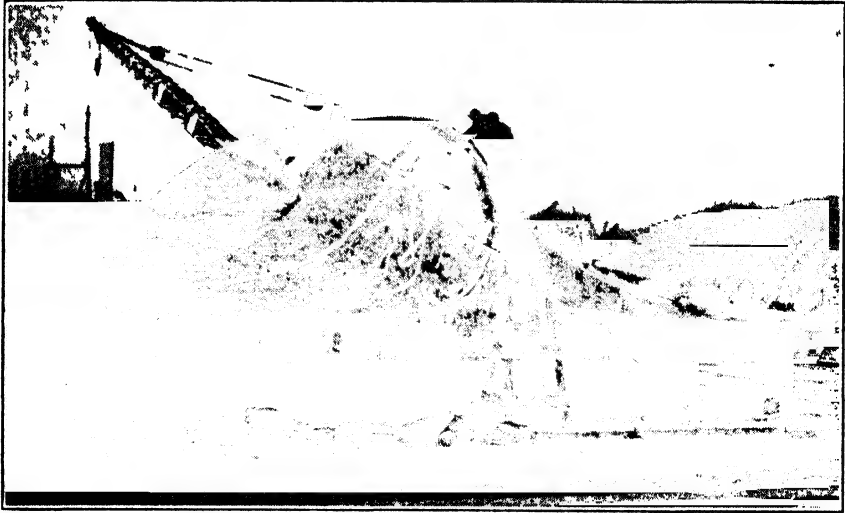
Fig. 18. The combination of upside down assembly, simple jigging and adequate crane service insures speedy, economical and sound workmanship.

delay and offered no obstruction to the regular flow of vessels from the barge shop. A comparison of the yard as shown in Fig. 22 above with that of the revised yard as shown in Fig. 23 will show the tremendous increase in working area without any increase in the river frontage or in the required equipment. In making provision for the new assembly line for the subchasers no new crane equipment was necessary and the short assembly tracks were put in at small expense. At this part of the yard the launching ways were on close centers and only two new ways had to be added. The position of the same vessel in the locations as shown in Fig. 22 would have required four more new ways.

Conditions similar to these had likewise been developed at the Wilmington yard where the congestion was even greater. The first assembly line was put in service at Wilmington late in 1940 and it was followed by another line built late in 1941. The sketch above shows the maximum capacity of this yard without assembly lines on the basis of work now under contract but with the addition of the assembly lines shown in Fig. 25 the capacity of this yard, in terms of actual structural tonnage in place on the building berths, has more than doubled.

It should be noted that with the addition of the assembly lines shown in Fig. 25 that there has been some increase in other facilities but that they
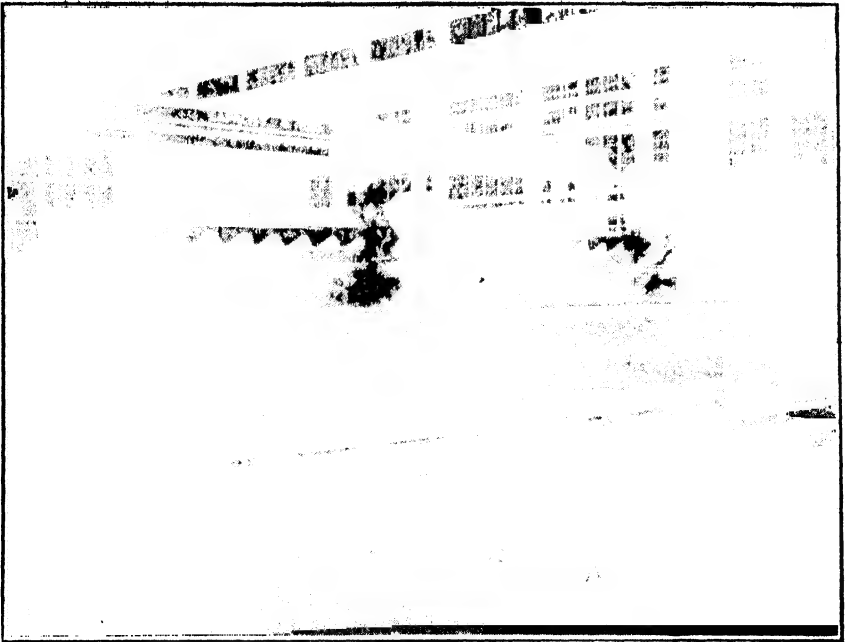
Fig. 17. Tilting tables permit flat work to be readily positioned for downhand welding. Equipment of this type should be portable.

are of rather limited extent A second crane track with two gantry whirler cranes was added as well as a new railroad siding No other changes in the yard were required so that the proportionate increase in the capacity of the yard was far ahead of the increased investment The yard at the time of these improvements was occupying all of the river frontage then available and the use of the assembly lines was the only practical method to improve the capacity without a major expenditure The more than doubled capacity was therefore obtained at an increase in cost of less than fifty per cent of the cost of the yard as shown in the original state.

The operation of such concentrated work is likewise carried out at lesser cost than where the work is spread out over a much greater area. Careful attention must be given to the planning of both the shop pre-assemblies and the erection at the building berths to insure a carefully scheduled operation and to prevent the undue congestion of material at any point in the system The movement of the vessels on the production lines permits the various groups of labor to be constantly engaged on the same operation with a resultant high efficiency both in quality of product and economy of performance.

The entry of the United States into the present world war has put new and greater demands on the shipbuilding yards which will be met in large part by the introduction of the assembly line methods on a much larger scale than those discussed above. These installations cannot be treated in full nor can their locations be given, but we will endeavor to show in a general way what is being accomplished.

All of the new yards under construction are based upon the principle of erecting the vessels in positions most favorable for efficient production
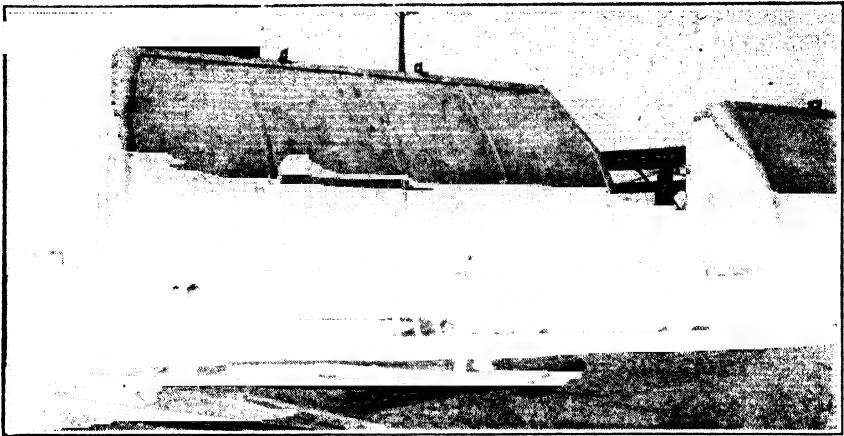
Fig. 18. Rake ends of lighters embody the most difficult part of the work but proper shop facilities send these fully assembled units to the erection site.

according to the sites available and all follow the idea of moving the ships to a single set of launching ways. Three such installations are shown in Fig. 26 and each type shown has been designed to meet special conditions which are largely dictated by the chosen sites and the desired results. As will be noted from a study of the sketches various handling facilities are used and it should be noted that there is a great flexibility in the combinations of assembly lines and crane equipment.

Several months prior to the declaration of war the author had occasion to develop a special type of assembly line as shown in Fig. 27. In this case it was found desirable to make provision for the transportation of the vessels from any erection berth directly to the launching ways. This precaution was to safeguard against delay in the event that machinery for any individual vessel might fall behind the delivery schedule.

Fig. 19. Inclined supports and large floor areas are provided while ample cranes juggle these massive sections into advantageous working positions.

In this case sixteen berths were so arranged that each one could feed directly to a transfer car for movement of the ship to the launching ways. By providing one large transfer car for the movement of the launching ways it was also possible to lay crane tracks on this transfer car and use it for the movement of cranes from one track to any other in order to concentrate crane power for unusually heavy lifts. Another feature of this design was the introduction of controlled launching by the addition of hoisting equipment to the launching carriage so that in case of necessity for inspection or other reasons the finished vessels could be hauled out of the water.
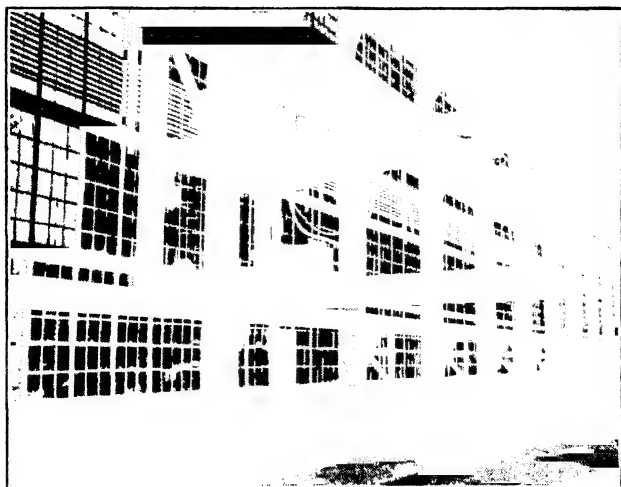
Fig. 20. A Lincoln Tornado welding unit mounted on a wall gantry covers 5000 square feet of floor where large units can be grouped for automatic welding.

The author received word recently that one of his friends was considering a yard somewhat similar to that shown in Fig. 27 and promptly sent him a photostat of the drawing shown here. A few days later a letter of acknowledgment was received of which the following is a partial quotation: "You will be interested to know that we have arrived at an almost identical solution to the problem. The chief variation being that we will place our ways one on each side of a tower whirler track with a space between that and the next pair to give additional working room, some storage room, and for the facilities such as locker and washrooms, foremen's offices, power transformers, etc."

This letter was of course most gratifying but it is also most indicative of the present trend in plant facilities. Welding has imposed demands upon us for new ideas and new methods and in order to get the greatest benefits out of welded construction we must develop welding plants that are as progressive as the welding process itself.

Assembly production lines will without a doubt play a large part in the production of ships in the next few years. In the next and final chapter we will endeavor to point out some of the benefits secured from the combination of a properly designed fabricating plant with production assembly lines.

Fig. 21. Eighteen ton side sections of carfloats shown on ground were designed to permit numerous full length runs of heavy automatic welding.

The Economic and Social Benefits of Welding Production Lines—In a summation of the numerous benefits derived from the proper coordination of a modern fabrication shop with the use of welding production lines we shall endeavor to give as nearly as possible figures which are the result of actual performance. Where it is necessary to forecast future results we shall endeavor to make only such assumptions as those which have a sound basis of facts behind them.

It is most difficult to show the value of a fabricating shop as compared to other shops but during the past year the author had an unusual opportunity to definitely establish such a comparison for the shop previously described. At the request of the office of production management a serious and widespread effort was made by the management of this plant to subcontract a portion of the fabrication of structural steel for ships in order
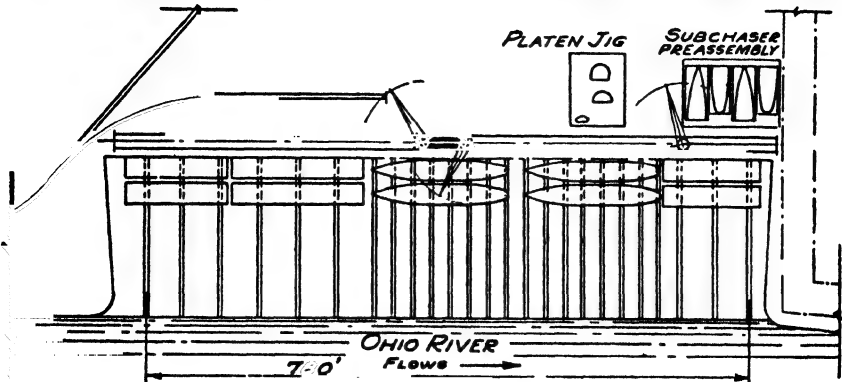
Fig. 22. Without production assembly lines the Neville Island yard would have a limited capacity as shown here.

Fig. 22. Without production assembly lines the Neville Island yard would have a limited capacity as shown here.

to accept additional defense work for which this plant was particularly well equipped.

The fabricated steel to be sublet consisted of barge hulls of fairly simple design and of all welded construction. Many shops were contacted covering practically all of those within a 300-mile radius of Pittsburgh. Some of the bigger shops were unable to quote due to prior commitments so that the bids received were representative of what we may call the average shop. Of more than fifty plants investigated only half a dozen bids were received. Considering only the three lowest bids, the results expressed in terms of excess price per ton over the selling price as already in the contracts were as follows:

Bidder A—Pittsburgh District..............$28.00 per ton excess.
Bidder B—Eastern Coast........................ 31.90 per ton excess.
Bidder C—Pittsburgh District.............. 40.30 per ton excess.

Average of these three bids..................$33.40 per ton excess.

These bids represented the only alternate source of supply available in the latter part of 1941 and serve as a direct measure of the economy of a properly equipped fabricating shop. During the year of 1941 the plant described herein fabricated a total of 47,000 tons of steel, which at a saving of $33.40 per ton, would show a total saving to the buyer of $1,569,800. Actually this saving would have been even more for the three low bidders did not have a combined capacity sufficient to produce more than half of the 47,000 tons.

The following is an extract from a letter in which we made the final report of the above survey to the O. P. M. office: "As a result of these many contacts and the resulting discussions of equipment and fabricating methods, we have arrived at the conclusion that the average structural shop
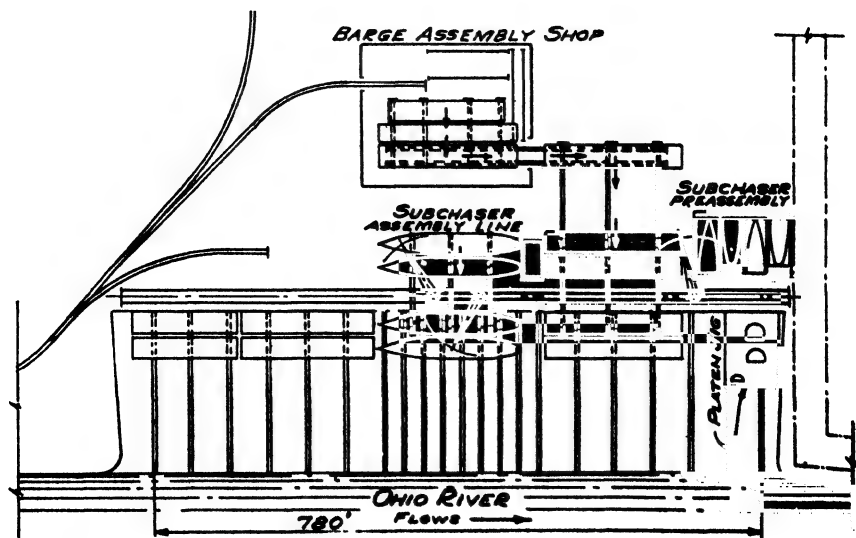
Fig. 23. New assembly line at center of yard together with the barge shop lines permits a maximum of erection in a minimum space.
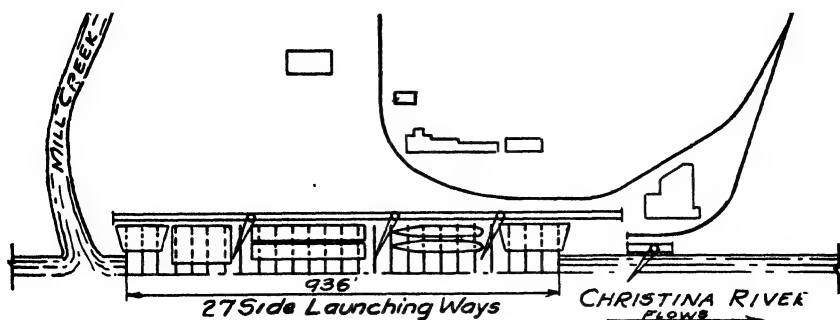
Fig. 24. Maximum capacity of Wilmington yard without assembly lines on the basis of work now under way.

does not have equipment suitable for the bending operations involved in ship construction. The average shop is likewise set up for riveted work and is not sufficiently experienced in welding and particularly in the shop assembly of the large sections predicated by the assembly line methods originated by Dravo to be competitive."

We believe that the above data is a true measure of the efficiency of a properly designed and equipped shop for the purpose intended:—the production of welded steel preassemblies.

The application of production assembly lines to ship construction has passed the experimental stage and enough work has passed over such lines in the past few years so that the saving in cost has been very definitely established. A conservative overall saving can be placed at ten per cent of the entire cost of the work. Many factors contribute to this saving but the greatest factor is that of repetitive effort on the part of the workman at each station. After the first few vessels are built on the line there is a marked step up in production due to the ability of the workmen to proceed without constant reference to the drawings. The fitters soon recognize each piece by its marking or appearance, the tackers know just what points require support and the welders soon develop a special technique for each individual weld.

A proper source of supply for the preassemblies permits these lines to guarantee the workman steady work without those layoffs which are inevitable when the ordinary methods of construction are used. All of these factors have been considered since the United States has entered the present world war and a large number of new production assembly lines are now under construction in many parts of the country. It is not possible to give specific data on these new plants nor is it possible to divulge their location but it is possible to state that at the present time shipbuilding contracts in excess of $1,500,000,000 have been awarded to plants which will use the assembly line methods described in this paper.

On the basis of a saving which we are assuming as extremely conservative at 10 per cent the use of assembly line methods on this defense work now under contract will show a direct saving of $150,000,000. In this day of figures of astronomical proportions that is not what we may call a large sum, but in the later years of reconstruction and adjustment it will be considered a real saving.

The allocation of contracts covering ship construction on assembly lines as cited above is only the beginning of continued awards for such work.
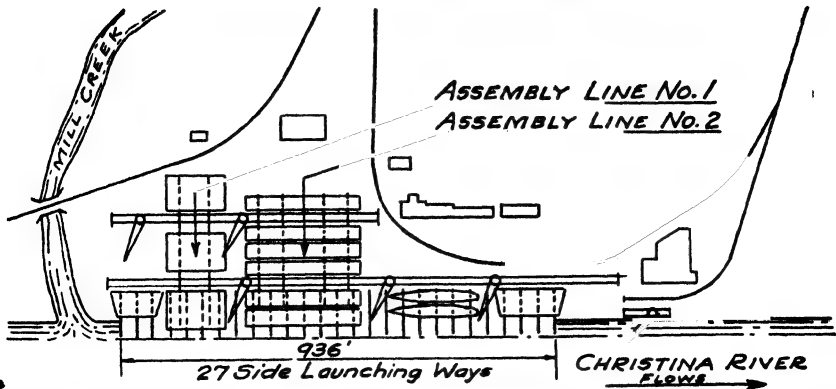
Fig. 25. The addition of the assembly lines has more than doubled the actual structural tonnage in place in the yard as compared with the same vessels shown on the ways in Fig. 24.

A news release in the Boston Herald under the date of March 16, 1942, contains the following information: "A tremendous new contract calling for the construction of 200 Liberty cargo ships by means of a secret adaptation of the automobile industry's assembly line technique was announced tonight by the Maritime Commission. A new shipyard, equivalent to 28 conventional shipways, will be built near New Orleans, and the 200 ships, each of 10,500 deadweight tons, are all to be completed before the end of 1943."

This project alone, with a total value of $350,000,000 will result in a similar saving of a minimum of 10 per cent, as indicated in reference to work previously allotted to assembly lines, or the not insignificant sum of $35,000,000. The secret adaptation of the assembly line is not as secret as inferred, nor is it a direct application of the automobile industry's methods. It is actually a duplication of the methods which have had several years of sound application in shipbuilding although the general idea of production lines was established in the automobile industry.
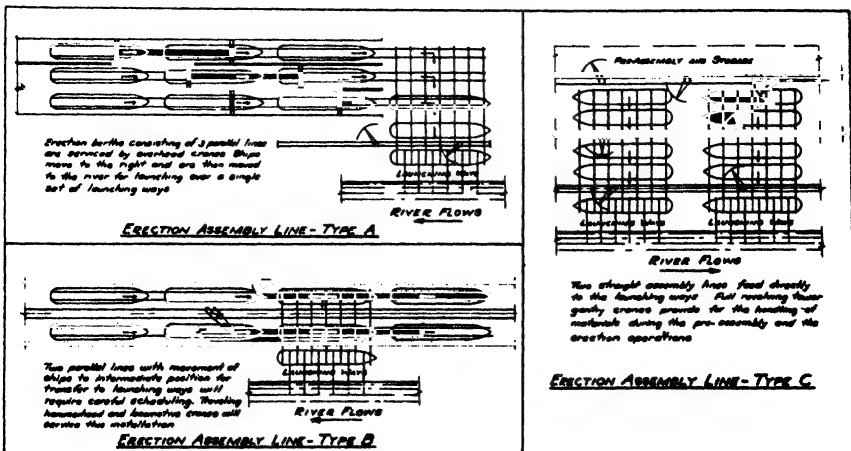
Fig. 26. Several types of assembly lines all tend to concentrate the erection in a central area with the movement of the vessels to a single set of launching ways.
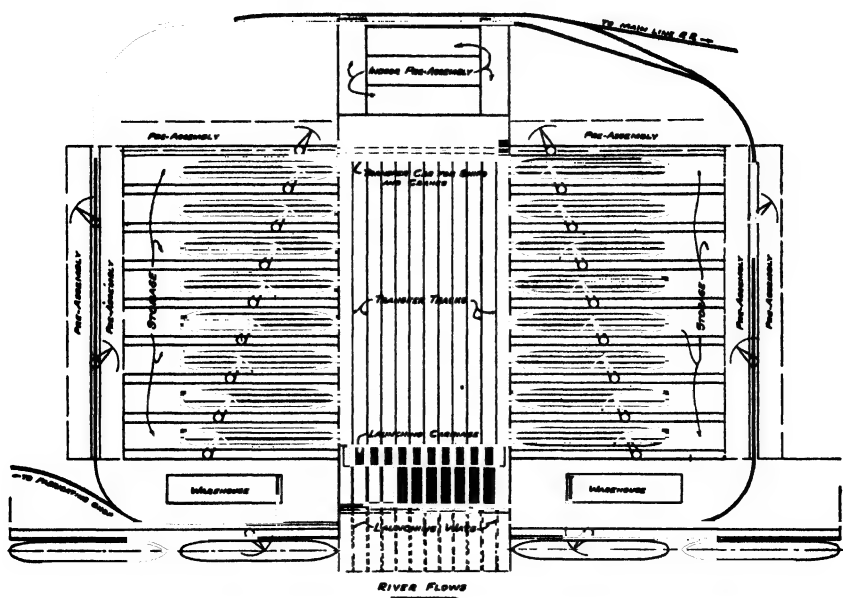
Fig. 27. This yard, while embodying the principles of assembly line methods, permits the movement of any vessel from its erection site directly to the launching ways.

The savings in the actual building of ships on assembly lines are not the only economies involved in such construction. Another news writer, Gordon Sanders, in an article also in the Boston Herald under the date of March 15, 1942, states that in 1937 there were in active usage in the United States only 10 shipyards having a total of 46 building ways. The rapid growth since then is set forth in an editorial in the January, 1942, issue of Marine Age which reads as follows: "In February, 1941, there were 170 building ways in this country capable of accommodating steel vessels of 300 or more feet in length in 45 private yards. Today, 65 private shipbuilding yards have 406 building ways engaged in building steel sea-going vessels for government and private account." This increase of 360 building ways represents the expenditure of a total investment of approximately $300,000,000, as the average allotment for new shipbuilding ways of the conventional and launching type for vessels of 300 feet and over has been costing from $750,000 to $1,000,000 per shipway. This figure covers all the facilities required for the erection and outfitting of ships but does not include structural fabrication shops and main manufacturing machine shops.

In connection with the allotment of the various ship contracts for assembly line construction there has been a corresponding increase in the requirements for erection and launching facilities. The work now assigned to such assembly lines would require a minimum of probably 150 conventional launching ways at a cost of $150,000,000. The use of the assembly line methods, as previously shown, permits a greater concentration of work and a consequent lesser expenditure which we may safely say is about 60 to 70 per cent of the usual cost or a saving in these new facilities of $45,000,000 to $60,000,000. A similar saving could have been effected in the expansion of yards during the period between 1937 and 1942 had the assembly line methods been given a wider adoption sooner which would

have saved approximately $100,000,000 of the $300,000,000 expended during that period.

This sudden and extensive adoption of the use of assembly line methods by the government will undoubtedly have an effect on all future shipbuilding. All of the yards now being built are being financed with government money and here again a large saving is being shown due to the economy of such installations. Savings of this nature all react to the general public welfare and will tend to speed the adoption of such methods by numerous shipbuilders in the future. The reports covering the shipbuilding market for 1941 showed a volume of work under contract on October 1, 1941, amounting to $12,000,000,000. It is safe to assume that at least half of this work could be produced on assembly lines so that the potential saving is very real. When business gets back to normal such methods will become imperative if a plant expects to remain competitive.

In summing up all of the above it is difficult to present the results without fear of accusation of exaggeration. The savings due to a modern fabricating shop have been very definitely established but at the present time entirely new shops are under construction where the experience gained here will permit of even better choice and arrangement of equipment which will result in even better performance and greater economies. Many of the new production assembly lines are being developed only after careful study of those already in operation. These new plants are being designed with full cognizance of the small comforts which can be incorporated into such facilities in order to make working conditions more pleasant for the workmen. Every effort is being made to observe all safety requirements so that accidents can be kept down to a minimum and the health of the men preserved. These items cannot be evaluated in dollars alone but they will contribute in a great degree to the defense effort and enable us to retain the American way of living.

Chapter IV—Operating a Plant Weldery

By Virgil Cochran

Assistant Superintendent, LeTourneau Co. of Georgia, Toccoa, Georgia

Virgil Cochran

Subject Matter: Casting and riveting is a thing of the past. The plant described has utilized welding completely even in the construction of its buildings which are made of steel building block. The blocks are panels which are welded into a unit with welded cross trusses. I-Beams are used in with concrete for flooring, and the roof is supported every 46 feet by 18-inch pipe columns. The roofing material is also made up of panels. The shop is divided into 5 departments of which fabricating and welding is one department. Shapes are cut by acetylene torch and metal is bent and shaped by rolls, presses and press brakes. Jigs of various kinds are made for positioning structures. Graduates of high schools are given training as welders. Each part of structure is designed for a certain weld, and the information is given on the drawings by using the symbols of the American Welding Society. Machine tools were produced by the plant in order to produce shells.

We have a method of joining metals in the United States today that few people realize the advantages and possibilities of. That is electric arc welding. We have seen the many uses which have been made of arc welding since the war started and wonder how long it would have taken to reach the present stage of welding if it had not been for the war.

Yet, what of the future? Will the progress of welding continue or have we reached the end? I believe we are just opening the door on future possibilities. Casting and riveting are a thing of the past as an important method of producing metal products.

I do not believe there is a plant in the United States that for its size utilizes the process of arc welding for the manufacturing of steel products more than the company for which I work.

The company for which I am working has been manufacturing heavy grading equipment by the arc welding method since 1931 when they started out on a shoestring with but a mere handful of men. Today, that company has grown to where it now has four manufacturing plants in the United States and one in Australia. The plant which will be discussed in this paper is one which was started November of 1938. Our company employs at this plant 2,000 men and women. The welding department employs an average of 250 welders.

As far as I know our plant is different from any other industrial plant in the world. My reason for making this statement is that everything connected with our plant is arc welded steel. The plant building itself is welded from steel. The employees' houses, the company-operated filling station, the hangar at the company's private airport, the office building, the warehouse, the company-operated dairy and cattle barn, water and fuel storage tanks, and the equipment used in the plant—everything has been made of steel joined together by arc welding. Surely the byword of our company is true, it is "welded together."
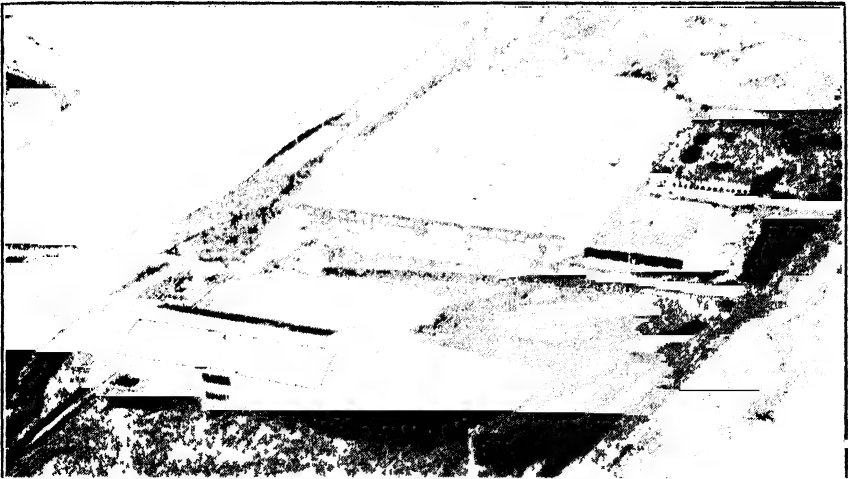
Fig. 1. Airplane view of main building, office and handling buildings.

Construction of Building—You might ask why is everything made of welded steel? The answer is for several reasons. The first one—because of one man's vision. Our president believes that regardless of how good a job is being done there is always a better way of doing it, and that is by welding. His vision of future construction of houses and all buildings is welded steel construction.

Second—the cost of construction is comparable to wooden construction while the upkeep and maintenance is negligible, consisting only of painting.

Third—simplicity of construction. The buildings can be constructed by the production line method using standardized parts.

Fourth—speed of construction. Using production line methods, a five or six room house can be built in less than a month. After looking at Fig. 1 you might wonder just how all these different types of weldings can be constructed of standardized parts. It is this: All of the buildings mentioned are made of steel building blocks of a standard size 44 inches wide by 88 inches long either 4, 6, or 18 inches thick. This panel is shown in Fig. 2. The panel is fabricated from two sheets of steel, 46 inches x 90 inches of 12-gauge material. These sheets are stamped in a mechanical press to a shape which will hold them rigid. They are then welded together facing each other with trusses bending from one sheet to the other. In the building these are arranged in such a manner as to make a self-supporting wall or roof. These are welded together in various combinations to get the desired results.

I will briefly describe the main plant building. It is a structure 368 feet wide by 598 feet in length. It is 24 feet high. The floor is 6-inch thick concrete with 6-inch Jr. I-Beams set in the cement every 23 x 46 feet. These I-Beams served as forms while the cement was being poured. At present it is a "ground" network for the welding machines.

The walls of the building are made of 6-inch thick "building panels" and has a double row of windows all the way around the outside, (See Fig. 3). The roof is made of the 18-inch thick building panels and is supported every 46 feet by an 18-inch pipe column. This pipe column is welded to the I-Beams in the floor and to the roof. To these columns are welded two rings on which swing two "boom" cranes. One is of two-ton capacity and

the other is 15-ton capacity. These cranes are swung from each column roof support so that the entire floor area is serviced by cranes. These cranes are also constructed entirely by arc welding. This network of "boom" cranes along with our fixtures for positioning structures for welding makes it unnecessary to have any overhead crane. Fig. 4 clearly shows how these cranes are arranged.

Our business is to manufacture heavy earthmoving equipment consisting mainly of scrapers, sheeps foot rollers, rooters and tournapulls. Each of these products is constructed entirely of a high tensile steel fabricated by arc welding. Fig. 5 shows our largest tractor and scraper combination which is capable of "scooping" up 60 cubic yards of dirt, carrying it for any distance at speeds up to 14 miles per hour and then spreading the dirt to any desired depth. This piece of equipment is operated entirely by one man.
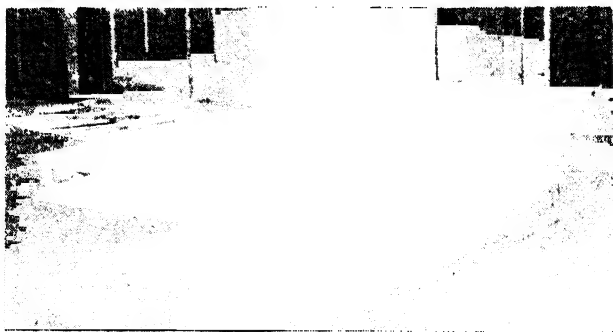
Fig. 2. Building panel showing two stamped sheets with welded cross truss.

Shop Organization—Our shop is divided into five major departments, each of which has several sub-departments within them. These major departments are: steel cutting and forming, machine shop, fabrication and welding, cleaning and painting and shipping departments. The superintendent is over the whole plant. Each major department is supervised by a general foreman who has several foremen and sub-foremen under his direction.

The purpose of our steel department, (See Fig. 6), is to store the large quantity of plates, angles, channels, sheets and bar stock necessary for fabricating our equipment, also to cut this steel to shape by torch cutting, shearing, punching or sawing.

Most of our material is cut with the acetylene torch either by hand or on a shape cutter which uses wood and metal templates and can cut various and odd-shaped pieces accurately and cuts them three at a time. This is a fast method of cutting, and the smooth, accurate cuts made by this method speed up the welding operations considerably. Another way of speeding up welding time and cutting costs is to bend and shape the metal as much as possible to save welding it. This is done in the steel department using presses, rolls and press brakes. By properly using this equipment the number of inches or feet of welding required can be cut in half. Figs. 7 and 8 show some of this equipment.

When the parts leave the cutting department they pass into a control room where they are stored until needed or else they are routed to the machine shop or welding departments. If at all possible, we machine our

parts before welding them and then use jigs and fixtures for lining up the parts. But when accuracy counts, we always machine the structures after welding.

Welding Fixtures—In the fabrication and welding departments our aim is "to get the best quality of work in the least time." To accomplish this, we use the largest and fastest electrodes that the material used can stand. Nearly all of the welding is done in the flat or fillet positions. Very little vertical and overhead welding, if any, is done in the plant. Everything we make is welded in positioning jigs which can be turned and rotated so that every weld can be made in the flat or horizontal position. Figs. 9 through 12 show a few of these welding jigs.

We have two classes of fabricating jigs, the set-up jigs and the welding jigs. Sometimes, though, these two are combined into a single set-up and welding jig. Our set-up jigs are used for setting up and tack welding the various parts together. The welding jigs are used for rotating the structure while welding.

The jig itself is a rigidly-braced skeleton framework on which are line-up pins, stops and clamps to hold the parts in the correct position while welding.

A good set-up and welding jig should have eight characteristics to make it successful. These characteristics are: 1, A jig must be light; 2, It must be strong and rigid; 3, It must be accurate; 4, It must be simple to use; 5, It must be so made that parts can be easily placed in it; 6, It must be made so that the finished structures can be easily removed; 7, It must be made so that all welds are exposed and easily accessible; 8, It must be correctly balanced and easily positioned.

There is but one main reason for using welding positioning jigs and that
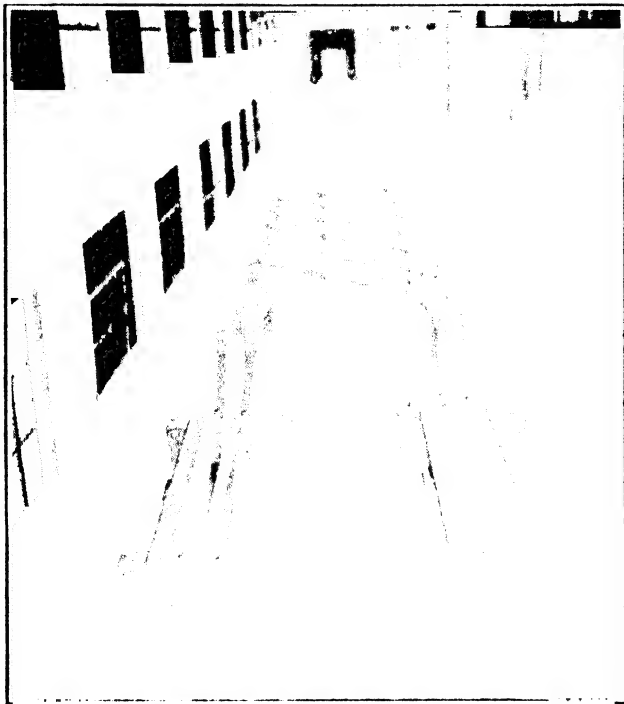
Fig. 3. Interior of plant in steel department.
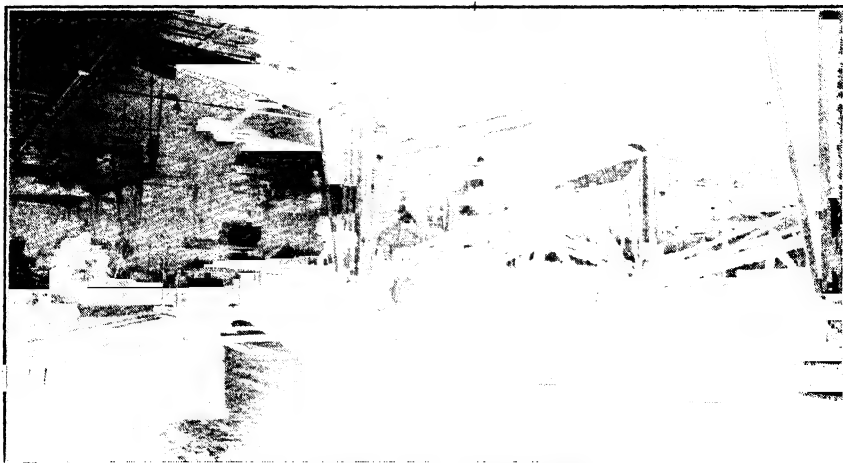
Fig. 4. Welding fabrication department.

is to cut costs. Besides lowering costs the positioning jig does five separate things. They are:

1. Increases quality and appearance:—This is accomplished because all the welds are made in a flat or horizontal position and run with large high-speed electrodes.

2. Increases speed:—Again this is accomplished by using large high-speed electrodes. Instead of using 5/32-inch and 3/16-inch electrodes in making the welds in a vertical position, a 1/4-inch or 5/16-inch and sometimes 3/8-inch electrode is used and the weld is run flat. We have cut our welding time by 50 percent in most places by using jigs.

3. Welding and set-up jigs make identical and uniform structures:—This is absolutely necessary on a production line where a completed unit is made up of prefabricated substructures. If these substructures are not all exactly the same, the main structure will not go together properly.

4. Welding jigs prevent warpage from expansion and contraction:—The welding jigs have clamps and stops which hold the parts to the desired shape. In many cases the jigs are made to preform the parts before welding to counteract the shrinkage and warpage due to welding.

5. Welding jigs permit the use of inexperienced operators:—This is especially beneficial at the present time when there is such a decided lack of experienced men. In a few months an operator can be trained to make satisfactory flat welds in a positioning jig.

We use many different types and sizes of positioning jigs both large and small and both power-controlled and hand-controlled. Some of these jigs handle structures weighing up to five tons.

Welding School—Of the approximately 250 operators working for our company only a very small handful have done any welding previously. We have found it much more satisfactory to train our own welders rather than to hire men who have already been welding at other occupations and other places. Our main reason for this is that in a great many places, the welders are accustomed to using only the smallest size rods, 5/32-inch, 3/16-inch and 7/32-inch, while in our work we utilize the larger rods, mostly 1/4-inch, 5/16-inch and 3/8-inch. All of our work is done by hand, using high-speed electrodes. In hiring men who have welded on other jobs, we have found it
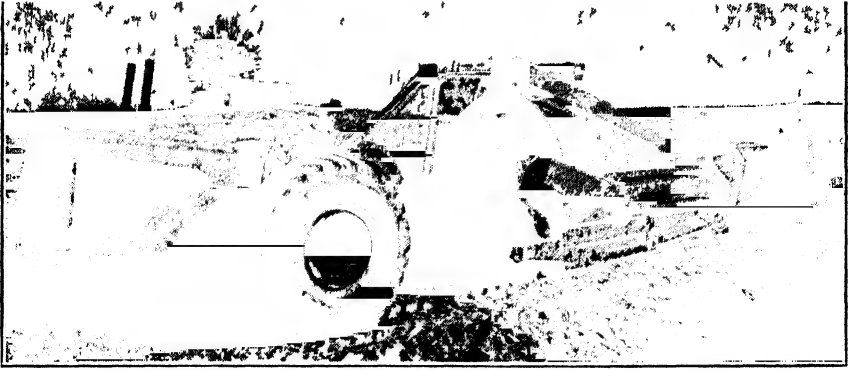
Fig. 5. 400-Horsepower Diesel Tractor with 60-yard scraper, every part arc welded.

difficult to get them to use these larger electrodes and follow procedures as we have set them up But by bringing in inexperienced men, training them in the way we want our welding done, and the methods and procedures used, we then do not have to worry about them In training our welders, we take high school graduates, preferably, in groups of ten and give them two weeks or 100 hours of combined welding practice, lecture room and study. They are put in the plant, given scrap plate materials and are first shown how to properly strike an arc at the desired location. They are then shown how to run flat welds, then fillet welds, proceeding on to semi-vertical, vertical and overhead welds, using various sizes and types of electrodes. For one hour a day, the instructor takes these men into a classroom where they study the terminology, theory and practice of welding When the men are practicing welding, the welds are broken open so they can see what is on the inside and they are given instruction on keeping good clean welds and not just on surface appearance.

Welding Tests—As welding operators go from one job to another, they are given tests to be sure that they can successfully do the welding necessary. In our type of work, we do not feel that it is necessary to give the men the
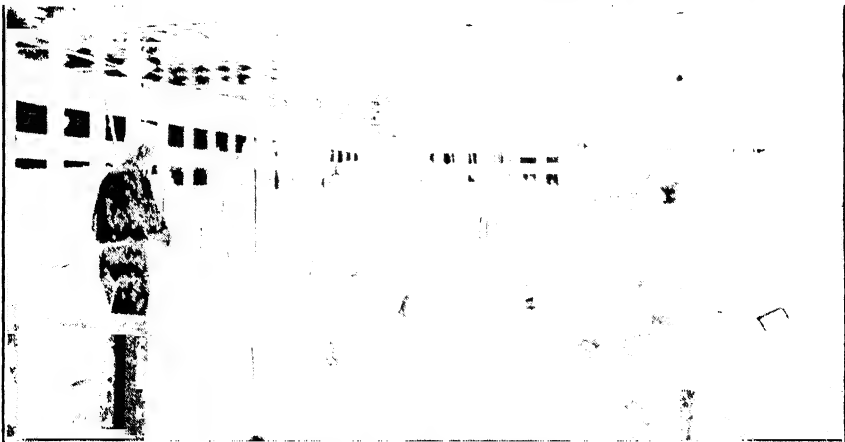
Fig. 6. Steel department.

customary tests of nick break, bending and tension. It is our opinion that for production welding it is not necessary for an operator to pass tension, bending or nick break tests, as these generally show only the quality of the weld metal. Our electrodes have been tested sufficiently to know what type metal they will give when deposited.

The welder, if he has been given the proper instruction and taught the proper procedures in welding, and if he has welding as his ambition, will do the best he can to deposit good welds. If this is done, and if the proper electrodes are used, the welding will be satisfactory. We have four classes of welders: Class I, which is flat and fillet welding with 3/16-inch and 1/4-inch electrodes; Class II, which is flat and fillet welding using large and high-speed electrodes; Class III, which is for fillet, semi-vertical, horizontal and overhead; Class IV, using any type of electrode in any position. In all of our tests, we use the following procedure: The plates are welded, using the given size rod at given amperage and in a specified position. These tests are then graded as follows:

Fig. 7. (left). Metal forming division of steel department. Fig. 8. (right). 700-ton mechanical press.

The time used by the operator to make each plate is recorded in seconds. The time for each plate is compared with the standard time allowed, and if the actual is in excess, the plate is rejected.

After the welds have been deposited on all the plates of a given test, the instructor, who gives the test, slags and brushes all the beads and removes the plates from the jigs. The weld size is determined by a gauge, and is recorded. Plus or minus one-sixteenth (± 1/16-inch) of an inch is allowed on the size of weld that was specified.

The plates are graded on the center four inches of weld which excludes one inch at each end of the six-inch plates. This allows the operator an inch of bead to get started and an inch to finish up.

The plates are then graded on surface appearance which is broken into two separate parts—undercut or over-lap and general surface appearance. The surface appearance is graded on the basis of roughness, irregularities of the edges, holes, taper of weld and regularity of ripples. A minimum grade of 80 percent is allowed. By 80 percent is mean that surface is 20 percent bad.

The amount of undercut is graded next. A minimum grade of 80 per cent is allowed or 20 percent of the four linear inches of weld can be undercut. The depth of the undercut also has a bearing on the grade. Since undercut

reduces the cross-sectional area of the parent metal, it is very objectionable and so is graded rather closely.

Overlap occurs infrequently, but, when it does, it is just as objectionable as undercut, and therefore is graded similarly.

At this point the plates are broken open from which grades on penetration, slag inclusion, gas holes, and porosity can be determined.

Since penetration in a weld is very important, a minimum grade of 90 per cent is allowed. An application of the fundamentals of good welding will result in good penetration, and because it does, the grading is rather tough.

Slag inclusions in a weld are a sign of poor welding technique, and at the same time, reduces the cross-sectional throat area of the bead greatly, resulting in less strength. Therefore, a minimum grade of 90 percent is allowed.

The greatest reducer of bead, cross-sectional throat area is slag holes. A large amount of gas holes result when using a short arc, especially "all position" rods. In accordance, a minimum grade of 75 percent is allowed. This grade seems rather liberal, but it is necessary due to the affinity of the rods and material for gas holes.

Hand in hand with the gas holes is porosity, produced by the same faulty technique. A minimum grade of 80 percent is allowed.

A summary of the items and their minimum grades follows:

Time	less than the standard time allowed
Size	± 1/16-inch
Undercut	80 percent
Surface Appearance	80 percent
Penetration	90 percent
Slag inclusions	90 percent
Gas holes	75 percent
Porosity	80 percent

If a grade is below the minimum on any one item, the operator fails the entire test. At a later date, preferably at least one month interval, the operator must repeat the entire test.

These definite characteristics are graded quite rigidly, and the operator cannot go from the work of one class to another unless he has satisfactorily passed the required tests.
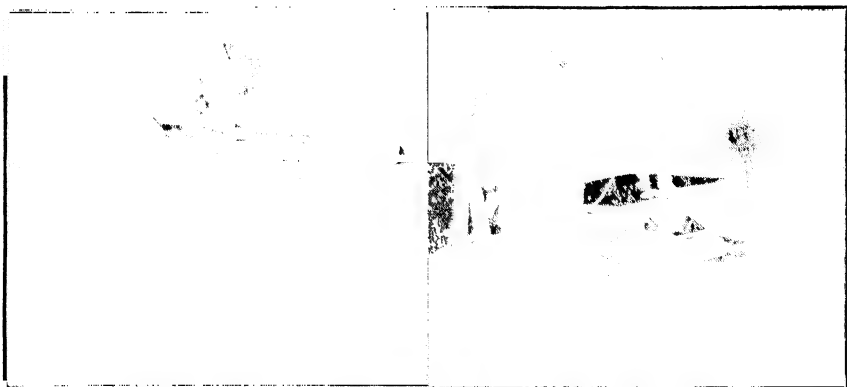
Fig. 9, (left). Rotating set-up and welding jig. Fig. 10, (right). Rotating jig to set-up and weld building panels.

Fig. 11, (left). Rotating jig for setting up and welding house plumbing system.
Fig. 12, (right). Double-acting positioning jig.

We require one element in our welding tests that, to my knowledge, is not being done elsewhere Our tests are all uniform and made in special jigs. Each test is timed and it must be welded at production speeds. If the operator fails to make the test within the time limit he fails the test.

We do this because we believe that a welder can usually pass a test if you give him enough time. But the tests should show what kind of welds an operator can turn out at production speeds.

Welding Procedures—We realize that most welders do not know what size welds are necessary on all of our equipment, and that they usually put just enough weld on to look good. Also our equipment must pass a rigid inspection set up by our service department which requires the necessary size of welds. Then, too, we use an incentive system for our welders which gives an accurate cost on all of our equipment. These requirements make it necessary to have an accurate system of control on our weld sizes. To do this we have set up a procedure system for all of our welding. The welding engineer, with the welding instructors, analyzes each structure which must be welded in the plant. They then decide what size each weld should be, what size and type electrode should be used in making each weld, what position that weld should be run in, what amperage should be used, and how many beads should be used in making the weld. This information is then shown on all of our fabrication drawings and is typed on procedure sheets which are given to each department foreman.

Each instructor knows these procedures by heart, and as he circulates through the department, instructing the welders on quality of work, he also instructs them in correctly following these procedures. This is another reason why it is not necessary for us to use experienced welders in our plant, because we can take inexperienced men, teach them the fundamental procedures of welding, give them copies of our written procedures which they can follow; thus, the quality and type of welding and the sequence of welds as made on the structures are not left up to each individual operator's opinion but are given to him definitely and must be followed.

Our procedure sheet has the job broken down into elements, and each weld is listed with all the information necessary to properly make that weld.

Looking at the information shown for each weld you will see something like this: $\frac{3}{8}$ F_2 G — 30

The interpretation of this is: Make a $\frac{3}{8}$-inch flat weld in two passes using a $\frac{1}{4}$-inch all position mild steel electrode at 300 amperes.

The first fraction always gives the size of weld, the letter following shows in what position the weld is made, the sub-number following shows the number of passes necessary to make this weld. The next capital letter tells which type of electrode should be used, and the two digit number following that is the amperage used without the last digit, thus 30 = 300 amperes; 40 = 400 amperes, etc.

The Welding Symbols—In the past, in nearly every organization, the engineering department designed a structure or piece of machinery either to be made of cast iron or of riveted construction, and in designing this piece of equipment they included in their drawings each minute detail, so the inspection department, production department and the actual worker knew exactly what was desired and proceeded on that basis. Harmony, from the engineering department to the worker, was possible through a common language—the "drawing."

With the rapid development of arc welding, and its application to all industries and their products, engineering departments, having been trained to other methods of fabrication, were at loss as to where to properly place a weld and what size bead should be used. This was usually left in the hands of the operator, who sometimes did an excellent job and other times was responsible for failures in welds.

Poor design by the engineering department caused failures that could often be blamed to some other department, which usually resulted in poor co-operation or friction.

The need for a common language in welding was imperative, and through the American Welding Society, engineers, inspectors, foremen and operators in all types of industries, a symbol system was devised which consists of simple signs and figures.

These symbols make possible: (1), location of each weld; (2), size of the weld; (3), type of weld (fillet, butt weld, beveled end, etc); (4), position of weld (vertical, horizontal, overhead, flat, etc.); (5), number of beads or passes necessary to make the weld strong enough for the stresses in that particular joint; (6), size of electrode for each pass; (7), type of electrode for each pass; (8), machine setting in amperes for each pass.
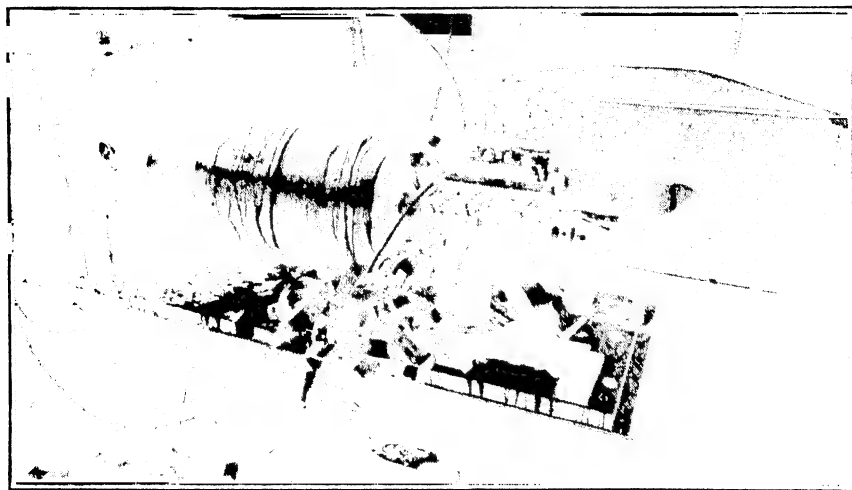
Fig. 13. Heavy-duty cutting by welded lathe.

Fig. 14. Lathe division of shell department.

The welding symbols adopted by our company are identical with those of the American Welding Society, with the exception that a few symbols have been added to make possible the application of the symbol system to the standards system now employed in this plant.

Three outstanding advantages of the symbol system have been found in our plant and they are as follows: (1), symbols convey to the operator, inspection department and cost department those requirements of the engineering department which are necessary for successful and low-cost production or construction; (2), symbols specifically instruct the operator with regard to the size, length of weld, etc., so that it will meet the requirements of the job it is to do, and also pass inspection; (3), symbols assist in helping the operator meet his standards, by specifically indicating the number of passes required as set up by both the engineering and standards departments.

Incentive System—As in any other process of manufacturing, cost is the most important matter. If your cost of manufacturing is high you lose money and go out of business. If you keep costs down your business succeeds and makes a profit. No matter how good welding procedures you have or how good welding operators you have unless these men work steadily and efficiently your costs will be high. In order to keep our men working efficiently we have installed an incentive system through which our men are paid a bonus according to the amount of work they turn out.

This is done by making careful time studies of all welding operations with a stop watch. To the actual time, correction factors are added for the man's ability and speed of welding, and for the effort that he puts into his welding. From this it is determined how many units go into the making of any weld of any certain size. A unit can be comparable to a minute, but instead of being a unit of time, it is a unit of work. Thus, a ½-inch fillet weld 10 inches long would take 20 units of work rather than 20 minutes of time.

Each operator marks up on a check sheet what he has done during the day. Beside each one of the elements listed is a standard unit of work. The

operator can then compute the number of units of work he has done during the shift. All men are paid a base rate for their particular job. On top of this for any work which they do that averages more than 60 units an hour, they are paid a premium. Each unit is equal to the base rate per minute. Each month the cost accounting department computes the total number of units turned out in each department. Against the number of units produced, they compute the amount of expense that goes into this department. Then, by dividing the total number of units produced into the total expense of that department, they can compute the unit cost. From the standards put on each operation of a given structure they know how many units go into the manufacture of one piece of equipment. Then by multiplying the total number of units in a piece of equipment by the unit cost they arrive at an accurate manufacturing cost for that particular piece of equipment for the previous month.

Manufacturing Shell Equipment—At the present time, one of the most important topics of the day is the subject of welding for National Defense. I am afraid most people, when they think of welding in National Defense, immediately think of shipbuilding and airplane manufacture. This is an entirely new field for welding in the United States and very little use of it has been made up until the time we started preparing for World War No. II. There are many other applications of welding for defense in which welding is just as important as in shipbuilding and airplane manufacturing, but very little thought is given to it. The phase of welding for defense I wish to discuss in this paper is that of an industrial manufacturing concern using its welding-fabrication department to produce the machine tools necessary to manufacture shells.

A War Contract—When World War No. II affected the United States, our plant was inspected by army ordnance engineers and we were asked to bid on a contract for machining 155-millimeter shells. Realizing that every plant in the United States must help out in order to win the war, our company placed a bid and was awarded a contract to machine 155-millimeter shells. In order to manufacture these shells, we found that it was necessary to more than double our quantity of machine tools, and in spite of the fact that we had the highest priority ratings, we found that it would
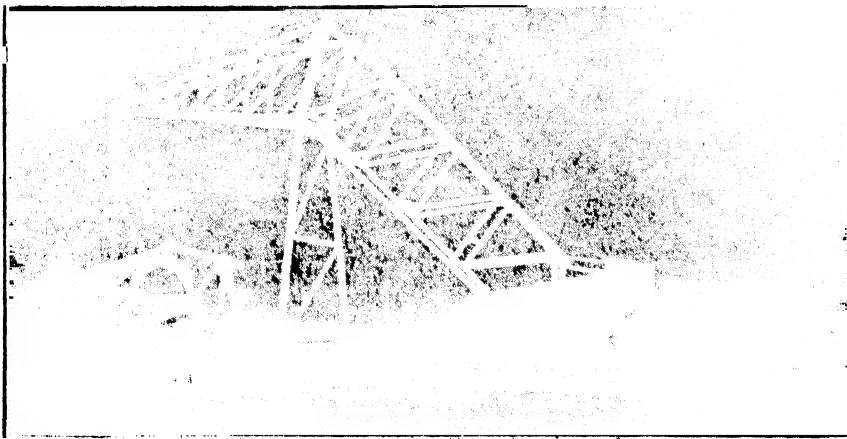
Fig. 15. Large movable crane holding load of 30 tons.

be impossible to secure additional machine tools in less than 12 months. Realizing the necessity of immediately starting to produce these shells, we decided to fabricate and make our own machine tools. In less than a year's time, we had produced the following equipment: 75 automatic lathes, 3 nosing presses, 3 shot blasts, 9 oil-fired heat treating furnaces, a conveyor system and 2 piercing presses for making shell forgings. Each of these structures has been made entirely of welded steel construction. The material was cut from standard steel sections and plates, shaped, welded and machined.

The advantages of these machines with similar machines which are on the market today are many. The first of these advantages is the speed of construction. This has been vitally necessary to us, as the time it would have taken us to secure the necessary equipment by buying it on the market would have required months of waiting for deliveries before we would have been able to start production.

The second advantage of this welded equipment is the cost of machines used in machining the forgings compared to the purchased price. We built by the welding method for approximately 1/3 of what similar machines would have cost if we had to purchase them
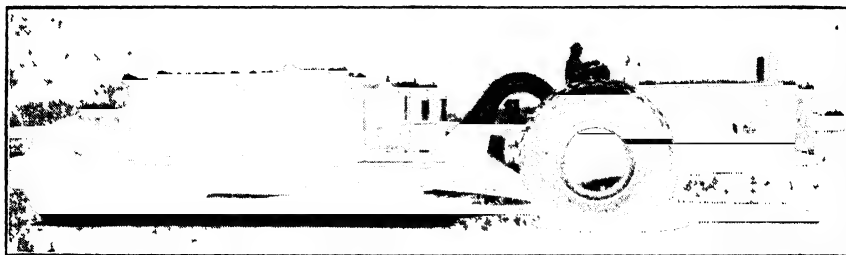
Fig. 16. Heavy-duty trailer with load of 75 tons.

Another advantage of manufacturing our machine tools is that we could make them of extremely heavy-duty construction. This allows for fast machining using heavy cuts and a minimum of maintenance. Also the machines do not have to be leveled and fastened to the floor. They are absolutely rigid and can be picked up and moved anywhere and they will still retain their accuracy. Another advantage is that we could design our equipment so that when our war contracts are over with, we could revise the tools very easily and use them in our regular production. This way there would be no loss to ourselves or to the government by the purchasing of special equipment. The last advantage of using our own manufactured equipment is that there is no shut-down waiting for replacement parts because we are able to manufacture everything for these machines in our own plant and can always keep a supply on hand. We feel that our electric welded machine tools are far superior and far stronger to any other equipment that can be purchased and they have allowed us to get into full production on government contracts while other plants are still waiting for machine tools to be delivered to them. Fig. 13 shows one of the welded lathes similar to those used in our shell department, while Fig. 14 shows a "bird's eye" view of the lathe section of the shell department.

Our welding for defense by no means ends with our manufacturing tools for shell machining. Let's look at some of the other equipment which can be used very definitely and is being used by the government in various
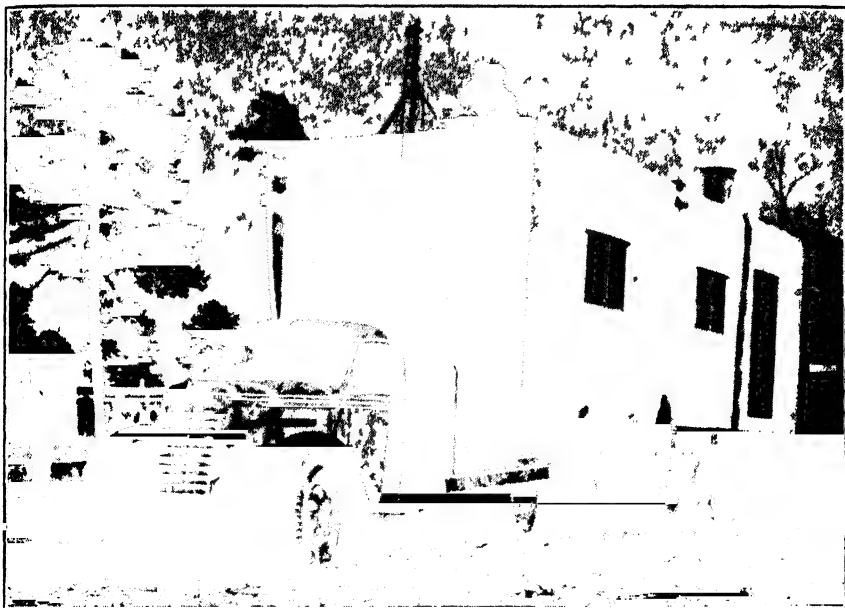
Fig. 17. All welded steel house being hauled to location.

phases of defense work Fig 15 shows a large movable crane, capable of picking up a load of 30 tons and carrying it at a speed of 14 miles per hour wherever it is necessary for it to go Can you imagine the various ways this piece of equipment might be utilized by army engineers in constructing and repairing bridges, handling heavy artillery, loading and unloading freight cars and handling whatever heavy equipment that might be necessary? It would not be out of reason to use this crane for removing bombers which have crashed in landing, from the field so that other planes which are waiting to land will have a clear field in which to do so Fig 16 shows a heavy-duty trailer capable of hauling a 75-ton load at speeds up to 13 miles per hour In a war where it is very often necessary to move heavy equipment in a very short time this could be used to a very distinct advantage for moving heavy artillery to a new position or carrying construction equipment from one place to another

One of the most serious problems which has been brought up in defense areas has been the matter of housing the workers For this purpose we have designed a one-room house, which contains a bathroom, kitchen, large closet, combination living, dining, and bedroom This is made in a single unit of welded steel just the right size to be set on a flat car or large trailer and can be carried from place to place All that is necessary to make this house livable is to set it on a flat area and connect a water line and sewer to the connections on the outside of the house It is then ready to be moved into and to be of service These houses, as shown in Figs 17 and 18 can be constructed in a very short time and will furnish very comfortable living with very, very little upkeep Practically 100 percent of our regular line of equipment is also being used for defense

It is not hard to realize how a scraper, shown in Fig 5 can be used in the construction of airports, roads, building sites, cantonments, railroads,

Fig. 18. All welded steel house set in position.

tank traps, bomb shelters, etc They can also be used to maintain airports that have been bombed and repair them quickly to get them back in shape for use

Conclusion—Aside from our regular production work and the making of machine tools for our own use, arc welding is also used extensively for other purposes

Briefly these are

1 Dies, punches and fixtures for forging and punching operations—every one of the hundreds of dies and fixtures used in our steel department have been made by arc welding Many of our simpler punches have been made by torch cutting the parts, facing the cutting edges and grinding to shape These require no other machining and are very economical

2 Drill jigs—all drill jigs and fixtures are fabricated from steel by arc welding

3 Salvage operations—Thousands of dollars are saved annually by salvaging machined parts that have been turned undersize or not according to the drawings At this plant a welder always "covers up" a machinist's mistakes

4 Maintenance—all of our machine repairing, pipework, duct work, etc is done by welding, saving much time and money

When we look back over the things that have been accomplished by the use of arc welding in this company and think of how these products, made through the use of arc welding, are helping to defeat the Axis, no one can say that "welding does not pay"

NOTE It has not been possible to show photographs or make any detailed statements concerning the equipment used in the shell department because of restrictions placed on us by the government

It has also been impossible to make cost comparisons on much of this material because of the radical designs used which cannot be constructed by any method other than arc welding

SECTION VIII
Containers

Chapter I—Liquefied Gas Storage Containers

By J. O. JACKSON
Chief Engineer, Pittsburgh Des Moines Steel Co., Pittsburgh, Pa.

J. O. Jackson

Subject Matter: A newly developed welded container for the storage of liquefied gas which costs less than 3 per cent of previous available types and which may be used to increase the annual volume delivered by the nation's natural gas pipe lines by 25 per cent at a saving of 4½ per cent of present total pipe line operating costs. Liquefied gas storage containers have been made possible because of electric fusion arc welding which alone can make seams in such containers which will withstand severe temperature variations and remain leakproof. Liquefied gas containers require only 1.8 per cent of amount of steel, 1.21 per cent of amount of ground space required by other containers. Total annual savings in industry through use of liquefied gas container would amount to $18,750,000.

Natural gas is usually transported from the gas fields to its markets by pipe lines often of considerable length. The demand for gas, particularly in markets where it is used for heating houses, is very seasonal and if pipe lines are designed for peak winter loads they become excessive in cost for the smaller demands during the warmer months. A saving would result if gas could be stored near market areas in sufficient quantity to permit the pipe lines to deliver gas at a more uniform rate throughout the year.

Gas has heretofore been stored in gas holders of the variable-volume types such as the telescopic water-sealed or the "waterless" sealed piston types or in spherical, blimp- or bullet-shaped tanks under pressure. Any of these types of containers would be excessively costly and would require large areas of ground space to store sufficient gas to materially reduce the winter peak demands of a pipe line even of small size.

Natural gas useful for domestic and industrial heating usually contains a large percentage of methane and smaller amounts of butane, propane, ethane, hydrogen, carbon dioxide, nitrogen and water vapor and traces of other gases. The butane and propane are usually removed at the source by oil absorption as they cause trouble by condensing in the pipe lines. If the water vapor and carbon dioxide are removed from the remaining mixture by drying and chemical treatment the methane may be liquefied by cooling it to below its critical temperature, about 116 degrees Fahrenheit below zero and subjecting it to a pressure of from 673 pounds per square inch absolute at its critical temperature to one atmosphere absolute at about 260 degrees Fahrenheit below zero. During liquefaction, the nitrogen and other inert gases may be removed, leaving substantially methane.
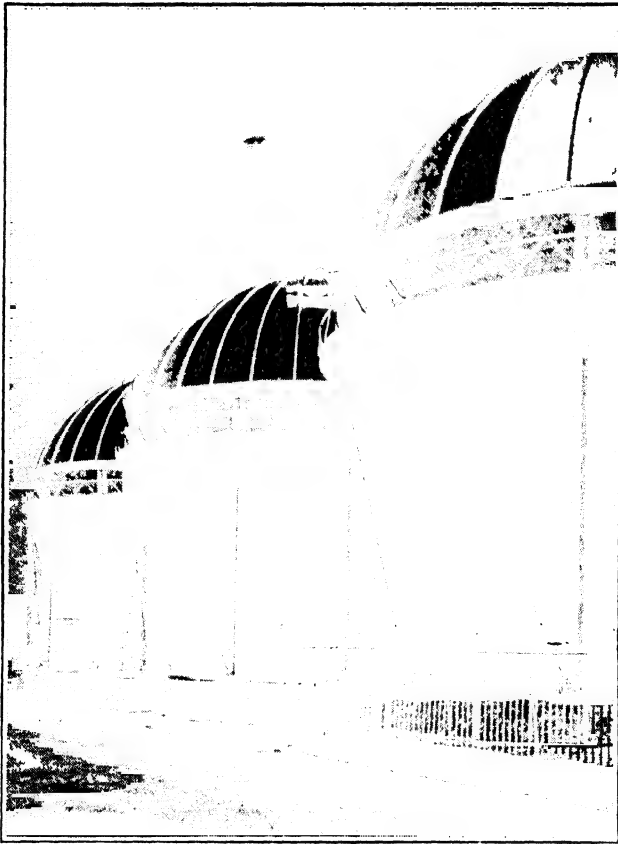
Fig. 1. Liquefied gas containers.

About 600 cubic feet of methane measured at standard conditions of temperature and pressure will occupy only one cubic foot of space when liquefied and if cooled to 260 degrees Fahrenheit below zero will exert no more vapor pressure on the inside of a container than the atmosphere exerts on the outside of it Very large quantities of gas can be stored in the liquid state at zero-gauge pressure in a comparatively small space. If gas is compressed at atmospheric temperatures to the volume it would occupy if liquefied, a pressure of about 9000 pounds per square inch absolute would be required.

The gas company serving Cleveland, Ohio with natural gas was experiencing shortages of gas in the winter seasons due to the demand having increased beyond the capacity of its supplying pipe lines. Studies indicated it would be less costly to increase the effective pipe line delivery by providing liquefied storage than by building an additional pipe line. A plant was designed and built with capacity to liquefy 4,000,000 cubic feet of gas per day and to regasify 3,000,000 cubic feet of liquid gas per hour. A storage capacity of 168,000,000 cubic feet of gas was provided in the form of three double-walled spherical containers, (See Fig. 1), 57 feet inside diameter and with about three feet of cork insulation between the two shells.

It was planned that the tanks would be filled during the fall months so that the stored liquid could be regasified and returned to the distribution mains during peak demand periods in the winter cold spells. Since warmer periods usually alternate with extreme cold ones, it was believed that enough additional gas could be liquefied and stored between cold spells so that the containers would provide about twice their capacity or 336,000,000 cubic feet of additional supply during the winter months.

Research work was done to determine the best material to use in the portions of the containers subjected to the intense cold. The following nickel alloy steel was found to be satisfactory and less costly than other materials considered:

Carbon	.08 to .12%
Manganese	.30 to .60
Sulphur	.045 max.
Phosphorus	.04 max.
Silicon	.10 to .20
Nickel	3.25 to 3.75%

This steel was deoxidized with a minimum of .08 percent aluminum added to the ladle and after rolling the plates were normalized at 1550 degrees F. After the above treatment, the steel had a grain size of 6 to 7 McQuaid and a Brinnell hardness of from 149 to 152.

Because of unusually large temperature changes and resulting expansion and contraction, and because of the necessity of having a leakproof container, welding was considered imperative. Welding permitted the construction of the lower part of the inner shell in contact with the insulation which would have been a serious problem with any other method. Satisfactory results were obtained by welding the special steel with electrodes having a composition of 25 percent chromium and 20 percent nickel. Best results were secured with a moderate amount of preheat, about 212 degrees Fahrenheit. Weld specimens were prepared in all required thicknesses and in all welding positions which consistently showed Charpy impact values when tested at 260 degrees Fahrenheit below zero of over fifteen foot pounds in either the weld metal, the fusion or the heat affected zones.

Drawing, Fig. 2, is a cross-section showing the general construction and drawing, Fig. 3, the dimensions and detail design of one of the containers. The inner shell is entirely supported by corkboard insulation in the lower part of the outer shell. The supporting columns and the outer shell are made of ordinary open hearth steel welded with mild steel coated electrodes. The entire weight of the container and contents is transferred to the columns through fillet welds between the outer shell and the column flanges. Granular cork insulation is used between the two shells in the upper part where supporting strength is not needed, the granular material being equally efficient as an insulating material and less costly and easier to place than corkboard.

Liquefied gas is pumped in and out of the container through the five-inch plug valve and the connecting pipe. The 18-inch pipe in the center of the container serves as a vent for evaporated gas and has a sliding fit at its upper end to accommodate expansion and contraction due to temperature changes. Both pipes are carried out in an insulated boot which increases the length of the heat path between the two shells. There is no metallic connection between the two shells. The plug valve may be operated from the top of the container by removing an insulated cover. The vent pipe is adequate to carry off the maximum volume of gas which can evaporate under any

condition and to return it to the gas system. It is provided with duplicate safety valves set to relieve the container if the pressure should for any reason rise above five pounds per square inch. In the event the two relief valves should both fail to operate, duplicate rupture heads are provided at the top of the inner sphere which are tested to burst at seven pounds pressure.

The space between the two shells is vapor-tight and a slight gas pressure is maintained by oil seals to prevent the entrance of any moisture-laden air which might impair the insulation. The liquid and vent pipes are provided with copper bellows-type expansion joints to permit settling of the inner sphere as it filled, causing the supporting insulation to shrink both from the increased pressure and the lower temperature.
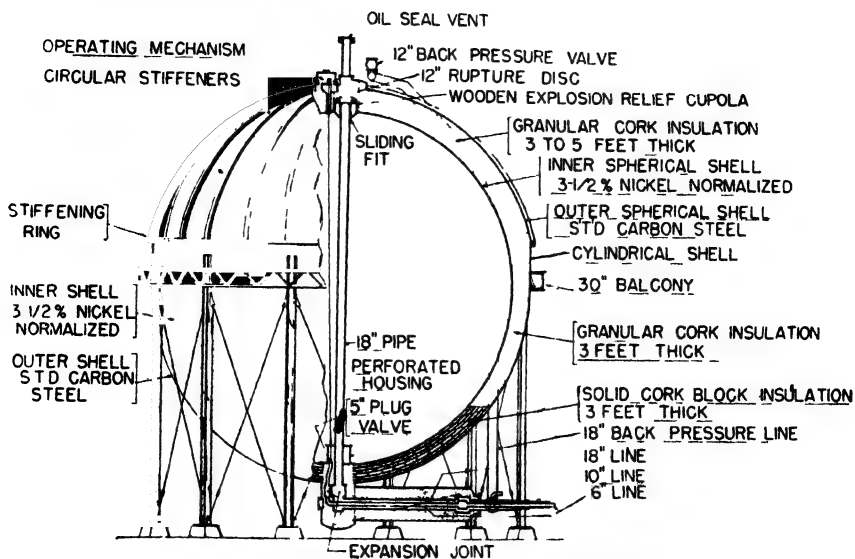
Fig. 2. Cross-section showing general construction.

The top part of the outer sphere is provided with stiffening ribs to enable it to withstand the slight vacuum which occurs with reductions in the barometric pressure the oil seals having sufficient back pressure to prevent venting.

When a container is first filled the liquefied gas evaporates until the inside metal and the adjacent insulation is cooled to the temperature of the liquid. The evaporated gas is reliquefied until temperature stability is reached, after which the rate of evaporation is very slow. The rate of heat flow from the outside to the inside of the container at average outside temperature is about 65 Btu per square foot per 24 hours. Each container has 13165 square feet of exterior surface. The daily heat transfer is, therefore, about 855,000 Btu. To evaporate one pound of liquid gas at –255 degrees F. requires 220 Btu. There would, therefore, be 3890 pounds or about 91,500 cubic feet of gas evaporated per day. Since each container holds 55,840,000 cubic feet of gas it would take over 600 days to completely evaporate all of the liquid from one container. The best vacuum bottle or DeWar flask if filled with liquefied gas would be completely evaporated in

a few days. The higher thermal efficiency of the Cleveland containers is due to the much smaller surface area per unit of volume. This ratio increases with size since the volume of a sphere increases as the cube of the radius while the area increases only as the square.

The completed cost of the Cleveland spheres including foundations, insulation, and accessories was $102,709 each. The net capacity of each container is 55,840,000 cubic feet. The cost was, therefore, $1839 per million cubic feet of gas stored. Each container required 287 tons of steel
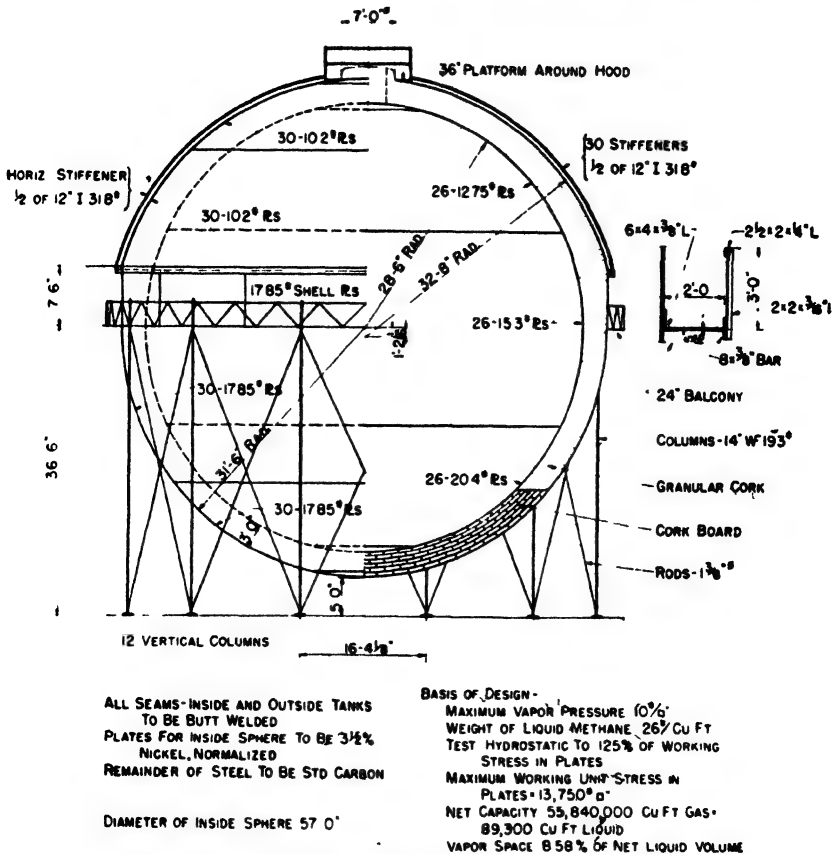
Fig. 3. Dimensions and detail design of a container.

or 5.13 tons per million cubic feet. More recent designs indicate that liquefied gas containers may be built with a net capacity of over 200,000,000 cubic feet and at a cost of $1314 per million cubic feet and requiring 4.3 tons of steel per million cubic feet. Drawing, Fig. 4, shows the design of a container of 212,560,000-cubic-foot capacity.

Water-sealed telescopic gas holders have been built in capacities of several million cubic feet. The largest all-welded water-sealed gas holder in Britain in 1938 had a capacity of 2,000,000 cubic feet and required over 880 tons of steel. This holder would cost about $225 per ton at present or $198,000 or $99,000 per million cubic feet and would require 440 gross

tons of steel per million cubic feet. A 502,000-cubic-foot holder cost $45,000 or about $89,700 per million cubic feet.

Waterless or sealed-piston types of gas holders have been constructed with capacities in excess of 20,000,000 cubic feet. A 21,000,000 cubic-foot waterless holder built in 1937 at Gelsenkirchen, Germany, was the largest in the world at that time being 262 feet 6 inches in diameter and 443 feet high. Its weight is over 5000 tons or 238 tons per million cubic feet. This holder would cost about $200 per ton or $1,000,000 total, or $47,600 per million cubic feet of capacity. A 12,000,000-cubic-foot waterless holder built for the Citizens Gas and Coke Co. of Indianapolis, Indiana, is 218 feet in diameter and 394 feet high and required 6,400,000 pounds of steel and 7,500,000 pounds of concrete. The cost is stated to be $700,000 or $58,300 per million cubic feet and it required 269 tons of steel per million cubic feet.

Pressure containers have been built in the form of spheres and bullets or blimps. In large capacities, spherical pressure containers are less costly than other shapes. The weight of spherical pressure gas containers per million cubic feet of free gas stored is theoretically the same for containers of any size or pressure. A 200-foot diameter spherical pressure holder has a volume of 4,190,000 cubic feet and at 34 pounds per square inch gauge pressure will release 9,680,000 cubic feet of gas. The total weight would be 5,250 tons or 543 tons per million cubic feet and would cost $1,050,000 or $108,400 per million cubic feet.

The relative costs and weights of various types of gas containers are shown in Table I.

TABLE I—RELATIVE COST AND WEIGHT OF GAS CONTAINERS

Type of Container	Approximate Maximum Size	Per Million Cu. Ft. of Cap. Cost	Wt. of Steel Reqd.
1. Spherical Pressure Containers	10,000,000 cu. ft.	$108000	543.00 tons
2. Water Sealed Holders	10 000,000 cu. ft.	$89000	440.00 tons
3. Waterless Gas Holders	30,000,000 cu. ft.	$47600	238.00 tons
4. Liquefied Gas Holders	200,000,000 cu. ft.	$1314	4.30 tons

The saving over the cost of the waterless gas holder, the next most economical type of container is $46286 per million cubic feet or 97.24 percent. The saving in the amount of steel required is 233.7 tons per million cubic feet or 98.2 percent. The saving in space occupied is about 3912 square feet ground area per million cubic feet of capacity or about 98.8 percent.

The above comparisons show that liquefied gas storage containers cost only a small fraction of previously available types. These comparisons accurately represent the container costs but they do not evaluate the over-all economic significance because in order to store liquefied gas it is necessary to first liquefy it, and in order to use it, the liquefied gas must be regasified. In the case of pressure storage, the cost of compressing is a comparable expense. With water-sealed or piston-sealed gasholders, compression is usually not necessary for storage but because of the necessarily low-storage pressures compression may be necessary after storage to overcome distribution pipe resistance. A comparison between the total estimated annual costs of a representative pipe line with various amounts of liquefied storage will show most accurately the economic importance of liquefied gas containers.

At the close of 1940 the investment in the natural gas industry in the United States was $2,414,490,000 or nearly double the capital employed in
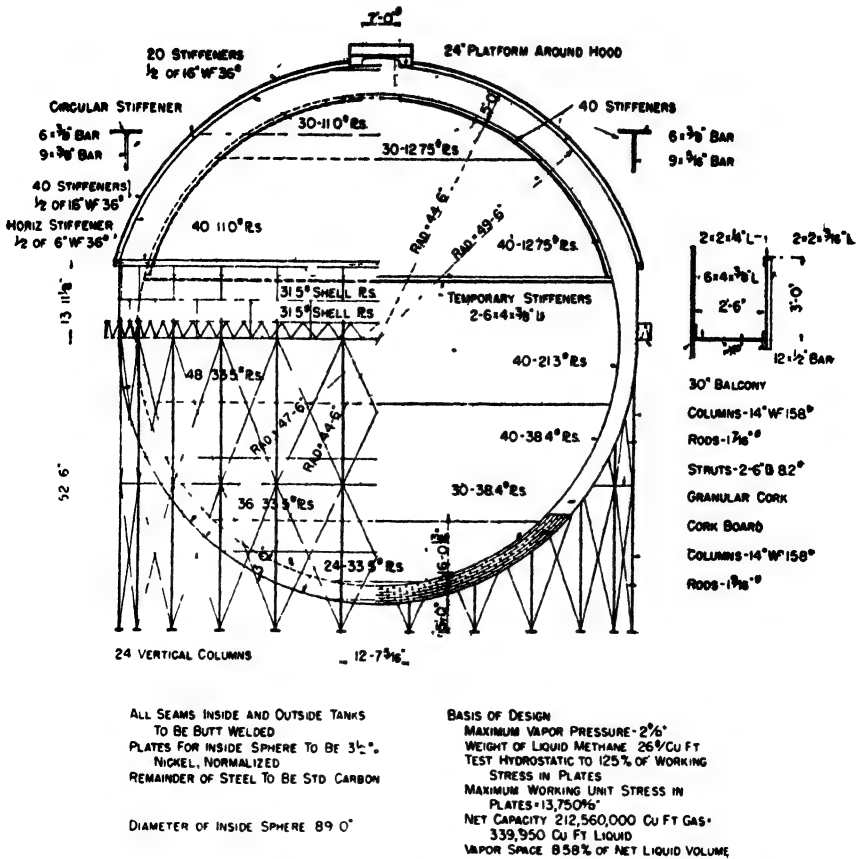
Fig. 4. Design of container having capacity of 212,560,000 cubic feet.

the manufacture of automobiles. Natural gas is available in 34 states serving areas with an aggregate population of 35,000,000. In 1941, 7,824,000 domestic, industrial and commercial customers used 1441.692 billion cubic feet for which they paid $492,717,000. Natural gas fields are found in 24 states and the production, transportation and distribution of natural gas gives employment to about 70,000 persons. The total length of transmission lines in the United States is 195,130 miles of pipe ranging from 6 to 26 inches in diameter.

A pipe line from Amarillo, Texas to Chicago, Illinois is 24 inches in diameter and 923 miles in length. It has ten compressing stations with a total of 71,250 horsepower. The capacity of this pipe line is 175 million cubic feet daily or 63,800,000,000 cubic feet per year. The total cost of the line is stated to be $75,000,000.

Because of the fluctuation in demand, pipe lines without storage serving domestic and industrial consumers deliver only a portion of their annual capacity. Table II, column 2, shows for the various months the ratio of gas delivered during that month to the capacity of the pipe line for a typical line serving industrial and domestic consumers. It will be noted that only in the month of December did the line deliver its rated capacity and the

average for the 12 months was 77 per cent of its rated capacity. Column 4 indicates that if storage is provided in the amount of 1.101 times the monthly capacity of the pipe line it can be made to deliver its full annual capacity. In this column, the minus signs indicate withdrawals from storage and the plus signs additions to storage. Columns 5 to 10 show similar figures for deliveries of 94 per cent, 88 per cent and 82 per cent of capacity respectively.

The cost of transporting gas in the pipe line referred to above is estimated to be as follows.

Capital Investment	$75,000,000
Annual cost of capital basis 4% bond and sinking fund interest, life 40 years, salvage value 10% and taxes at 6% is 10.9471%	8,210,000
Labor and supervision, 71250 h.p. at $5.25	374,000
Maintenance and operation, 71250 h.p. at $1.54	110,000
Fuel at 10¢ per MCF, 71250 h.p. at $8.78	625,000
Total Annual Cost	$9,319,000

The total annual delivery without storage is 77 per cent of the annual capacity of 63.8 or 49.1 billion cubic feet. The cost per MCF (1000 cubic feet) is 931,900,000 cents divided by 49,100,000 or 18.96 cents per million cubic feet.

Table III shows the comparative cost of liquefaction, storage and regasification and the total cost of transporting gas including the storage cost for various amounts of liquefied storage. It will be noted that the cost per thousand cubic feet of added annual delivery resulting from the storage is a minimum of 5.95 cents at 82 per cent of capacity reaching a maximum at 88 per cent of capacity then decreasing to 13.42 cents per thousand at 100 per cent of capacity. While it is true that the lowest cost per thousand cubic feet of added annual delivery occurs for the smallest indicated amount of storage this does not represent the most economical storage capacity when considering the total pipe line costs. The cost per thousand cubic feet of total gas delivered ranges from a high of 18.96 cents per thousand without any storage to 17.66 cents per thousand cubic feet with sufficient storage to permit operation at 100 per cent of annual capacity.

If we assume that the cost or value of the gas at its source is 10 cents per thousand cubic feet, the total delivered cost from the line without storage is 28.96 cents per thousand cubic feet. On the basis of sufficient storage to permit an annual delivery of 100 per cent of capacity the cost including the value of the gas at its source is estimated to be 27.66 cents per thousand cubic feet. This represents a saving of 1.3 cents per thousand cubic feet or 4.5 per cent of the delivered cost of the gas from a pipe line without storage.

Since the total value of gas delivered annually was stated to be $492,717,000 the saving would be 4½ per cent of $492,717,000 or $22,200,000.

It was also stated that the total gas deliveries in the United States were 1,441,692,000,000 cubic feet. The total saving calculated on this quantity at 1.3 cents per thousand cubic feet is $18,750,000 per year.

The total volume of storage which would be required so that all of the nation's pipe lines could operate at full capacity based on Table 2 is 170 billion cubic feet. This amount of storage if provided in waterless holders would cost $1,700,000,000. It obviously would be uneconomical to spend this amount to save $18,750,000 per year. Liquefied storage could be pro-

TABLE II—PIPE LINE DELIVERY RATIOS AND STORAGE FACTORS AT VARIOUS TOTAL ANNUAL DELIVERIES

(1) Month	(2) Capacity Ratio	100% Capacity		94% Capacity		88% Capacity		82% Capacity	
		(3) Delivery	(4) Storage	(5) Delivery	(6) Storage	(7) Delivery	(8) Storage	(9) Delivery	(10) Storage
January	.924	1.200	− .200	1.134	−.134	1.055	−.055	.984	+.017
February	.955	1.240	− .240	1.165	−.165	1.090	−.090	1.017	−.017
March	.912	1.185	− .185	1.113	−.113	1.042	−.042	.971	
April	.759	.985	+ .015	.925		.814		.807	
May	.665	.863	+ .137	.810		.712		.708	
June	.614	.798	+ .202	.750		.660		.654	
July	.542	.703	+ .297	.660	+.135	.582		.586	
August	.595	.772	+ .228	.725	+.275	.678		.633	
September	.605	.785	+ .215	.738	+.262	.691	+.236	.643	
October	.765	.993	+ .007	.933	+.067	.874	+.126	.814	+.028
November	.904	1.176	− .176	1.105	−.105	1.033	−.033	.963	+.037
December	1.000	1.300	− .300	1.222	−.222	1.142	−.142	1.065	−.065
Total	9.240	12.000	−1.101 +1.101	11.280	+.739 −.739	10.373	−.362 +.362	9.845	−.082 +.082
Average	.770	1.000		.94		.86		.82	

TABLE III—COMPARATIVE COST OF TRANSPORTING GAS WITH VARIOUS AMOUNTS OF LIQUEFIED STORAGE

Total Storage, billions of cu. ft.	0	.341	1.90	3.88	5.78
Annual Delivery, % of Capacity	77%	82%	86%	94%	100%
Total Annual Delivery, billion cu. ft.	49.1	52.3	56.20	60.00	63.80
Liquefaction capacity required, million cu. ft. per 24 hours	0	6.38	41.3	48.2	52.0
Added Annual Delivery, billion cu. ft.	0	3.20	7.10	10.9	14.7
Capital Investment in Containers, millions of dollars	0	$.448	$2.50	$5.10	$7.60
Capital Investment in Liquefaction Plant, millions of dollars	0	$.958	$6.20	$7.23	$7.80
Total Capital Investment, millions of dollars	0	$1.406	$8.70	$12.33	$15.40
Annual capital cost (1) of containers at 10.524%	0	$47,300	$264,000	$537,000	$800,000
Annual capital cost (2) of liquefaction plant at 10.842%	0	104,000	672,000	784,000	845,000
Labor and supervision, estimated	0	20,300	25,100	32,300	43,100
Maintenance and operation, estimated	0	4,000	27,000	31,000	34,000
Fuel at 25c per MCF = $43.95 per million	0	15,000	83,500	170,000	254,000
Total Annual Cost	0	$190,600	$1,071,600	$1,554,300	$1,976,100
Cost per MCF added annual delivery	0	5.95c	15.1c	14.25c	13.42c
Total Annual Cost including pipe line, millions of dollars	$9.381	$9.510	$10.391	$10.873	$11.295
Cost per MCF, total gas delivered	18.96c	18.2c	18.45c	18.10c	17.66c
Cost per MCF, including cost of gas at 10c per MCF	28.96c	28.2c	28.45c	28.10c	27.66c
Saving over no storage, cents per MCF	0	.70c	.51c	.86c	1.30c
Per cent saving over no storage	0	2.42%	1.41%	2.97%	4.50%

(1) Based on reference (19) Life 50 years, bond and sinking fund interest 4%, salvage value 20%, taxes 6%, factor = 10.524%.

(2) Based on reference (19) Life 40 years, bond and sinking fund interest 4%, salvage value 20%, taxes 6%, factor = 10.842%.

vided for approximately $223,000,000 or at a total saving of $1,527,000,000 over the cost of the best previous type of container. On the basis of 4 per cent interest the annual saving of $18,750,000 would justify a capital expenditure of $468,750,000 or over twice the cost of the liquefied storage.

Conclusion—1, Liquefied gas storage containers have been made possible because of electric fusion arc welding which is the only known method of making seams in such containers which will withstand the severe temperature variations and remain leakproof.

2, Liquefied gas containers in the most economical sizes which have been designed cost only about 2.76 per cent as much as previously available types.

3, Liquefied gas containers require only about 1.8 per cent of the amount of steel for their construction as is required by the most economical type previously available.

4, Liquefied gas containers require only about 1.21 per cent of the ground space required by the best previously known containers in this respect.

5, Liquefied gas containers may be used to increase the effective capacity of gas transportation lines with the maximum result that the lines may be made to deliver their full annual capacity and at a saving of approximately 4.5 per cent of the cost of all gas delivered by the system.

6, The total annual saving which should result from the complete use of liquefied gas storage in pipe line distribution systems only, is estimated to be $18,750,000 which capitalized at 4 per cent indicates the economic value of liquefied gas containers in this industry to be $468,750,000.

7, Other advantages of the use of liquefied gas storage containers are that they permit continuous operation of gas wells, pumping facilities, and gas transmission lines at their optimum capacity and they provide large quantities of stored gas near the market as a reserve, reducing interruptions to service because of failure of pumping facilities, washouts of pipe lines, and other causes.

Chapter II—Design and Production of Heat Exchangers

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Subject Matter: Developments in the design of heat exchangers with particular reference to storage water heaters. The design and production of heat exchangers and pressure vessels has been simplified and improved by the use of arc welding. The writer developed a method of producing welding neck flanges to meet storage heater requirements by fabricating them from bar stock. A full description of the method is given. The writer estimates the reduction in cost in favor of welded design to be $39.74 or 27½ per cent. The saving by weight of materials is estimated to be 7 per cent.

The design and production of heat exchangers and pressure vessels has been simplified and improved by the use of arc welding. Not only has arc welding enabled the designing engineer to use a lighter weight of raw materials, to produce a better product than was possible with previous methods of construction, but it opens up an almost unlimited field for types of construction which were practically impossible before the advent of welding.

In designing heat exchangers, the engineer is confronted with the problems involved in designing for safe internal working pressures varying from vacuum conditions to pressures of 2000 pounds per square inch or more; for temperatures ranging from 200 degree F. or lower below zero to 1000 degree F. or higher above zero; and for corrosive conditions requiring the use of almost every material capable of being formed and welded.

The construction involved is frequently of such nature that the old methods of fabrication by means of castings and riveted designs are practically out of the question, either by virtue of excessive cost or of the difficulties of producing a satisfactorily finished product. Areas exposed to high operating pressure should be designed as compact as possible to reduce the total pressure area, thus holding the total pressure load to a minimum. Parts subjected to wide variations in temperature should be as flexible as possible. For these and many other conditions, welding is now an indispensable tool in the hands of the designer and manufacturer of heat exchange equipment.

In this paper, it is proposed to touch very briefly on the general subject of heat exchangers, their use and application, and, selecting one regularly manufactured piece of equipment, point out the differences in design necessary in changing from riveted to welded construction and the benefits resulting therefrom.

What Are Heat Exchangers—The name is really self-explanatory. Heat exchangers are used to effect the transfer of heat from any liquid, gas or vapor to another of these media.

A tubular heat exchanger consists, essentially, of a number of relatively

small-sized tubes enclosed in a shell or casing, with means provided to keep the two fluids entirely separate from each other with absolutely no inter-leakage and, at the same time, comply with the factors involved in the efficient design of such equipment, namely relatively high velocities to increase the rate at which heat is transferred from the one fluid to the other, and relatively low pressure losses to reduce pumping costs and loss of head pressure.

Large numbers of heat exchangers are used in the oil refining and chemical industries, in central power stations and in the food industry. In fact, they appear in some shape or form in almost every industry and most large buildings.

In some cases, exchangers are used simply to get rid of unwanted heat. For instance, it is necessary to remove the heat, generated by friction, from lubricating oil circulated to large bearings in turbines, generators and prime movers in general. In heat treating steel plants, heat from the quenching oil generated by quenching quantities of steel from temperatures of about 1600 degree F. must be removed. In internal combustion engines, the jackets must be kept cool, otherwise the engine would be quickly overheated and ruined. The life of the engine is greatly prolonged by using clean or preferably distilled, cooling water, and the heat absorbed by the jacket water is removed by circulating it through a water-cooled heat exchanger, using any available supply of cooling water. These are all examples of unwanted heat, and while in some cases the heat can be transferred to some other fluid and used to advantage, the conditions are such that it is usually more practical to transfer it to a suitable source of cooling water and discharge it to waste.

Another example of unwanted heat occurs in distillation processes where the latent heat of steam or vapors must be removed to condense, or reduce to the liquid phase, the products of distillation. Frequently, a part of this latent heat is used to economic advantage in preheating the cold feed to the evaporator, or to vaporize other liquids which can be evaporated at a temperature lower than that of the vapors being condensed. After recovering all the latent heat which can be used in this manner, in a specially designed heat exchanger or condenser, the balance is removed in a vapor condenser. It is frequently desirable to cool the condensed products from the condensing
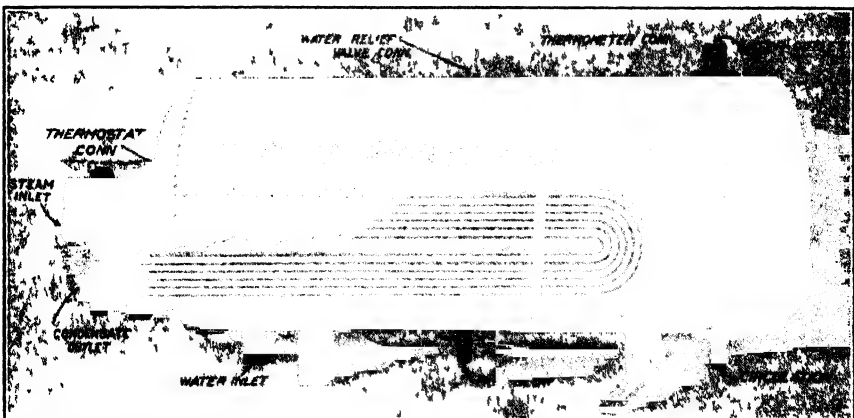
Fig. 1. Riveted type storage heater.

temperature to approximately room temperature, and this is accomplished either by making special provisions for condensate cooling in the vapor condenser itself or by subcooling the condensate in a separate liquid cooled heat exchanger.

In central power stations, steam is generated at high pressures and expanded through a turbine, and a portion of the heat energy therein is converted into useful work. A small percentage of this steam is "bled" at several points from the main turbine and used to preheat the condensate stream to a relatively high temperature before its return to the boilers. However, after expanding the steam to the lowest practicable pressure, the latent heat still remaining must be removed by means of a water cooled condenser so that the necessary vacuum may be obtained, and the condensate recovered to be returned again to the boilers. All heat rejected to the cooling water must be considered as lost.
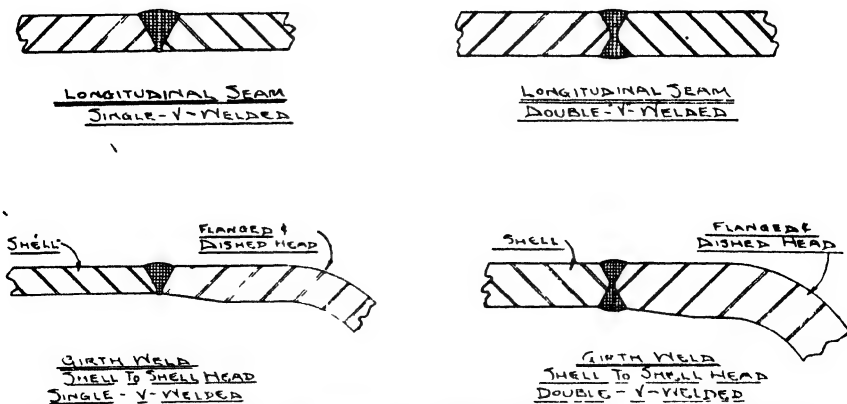
Fig. 2a. Typical details of longitudinal and girth seams for welded storage heaters.

The amount of fuel used, either directly or indirectly, by the nation's industries, to generate heat which must subsequently be gotten rid of, is very large and constitutes a considerable drain on our natural resources. However, engineers, scientists and others engaged in the design and maintenance of industrial plants are fully aware of this fact, and the use of heat exchangers is rapidly increasing wherever they can be used to economic advantage.

For instance, in the oil refining industries, a great deal of the heat generated from fuel is recovered and used again by the efficient location of heat exchangers in the various fluid streams to transfer heat from one fluid to another. Hot liquids or vapors are passed through one circuit of a heat exchanger, heating or vaporizing another liquid entering the other circuit at a lower temperature.

Textile plants and laundries are large users of hot water at temperatures ranging up to 200 degree F. or higher. Having served its purpose, the water is of no further value and is rejected to waste. In this case, it is not only practical but highly economical to recover a large percentage of the heat content of the waste water and transfer it to the incoming fresh water. This is accomplished by a special form of heat exchanger known as a preheater or heat reclaimer. An installation of this type reduces the fuel consumption of

the entire plant, representing not only a saving in dollars and cents to the owners but a worth while contribution to the conservation of our natural resources.

Instantaneous and Storage Heaters—One of the simpler, but by no means less important, forms of heat exchangers is that used in the transfer of heat from steam to water for the production of hot water for various industrial and domestic purposes. Such heaters may be divided into two separate groups, instantaneous and storage. Instantaneous heaters are used when the demand for hot water is fairly uniform and steady, for instance, in heating turbine condensate in central power stations, recirculating water in swimming pools, keeping overhead sprinkler tanks above the freezing temperature and for supplying hot water radiation to large buildings, using steam from the low pressure boilers.

In cases where the hot water demand is irregular, the storage type of heater is desirable and much more economical to operate. Such conditions occur in hotels, schools, hospitals, institutions, industrial buildings, etc., where hot water is needed for showers, lavatories and general purposes; in laundries, where large quantities of hot water are required in the laundering of clothes; and in textile mills, bleacheries, dye houses, meat packing houses, etc., some of which use large quantities of hot water with an uneven demand rate.

The principle involved in the design of a storage heater is to provide ample storage capacity to supply sudden hot water demands and to proportion the arrangement and amount of heat transfer surface to produce the required amounts of hot water so that steam for heating the water will be drawn from the boiler at a fairly uniform rate without violent fluctuations. This requires a rather carefully detailed study of the requirements of each installation. A storage heater to be installed in a hotel, for instance, will be required to supply hot water at, say, 180 degree F. for a known number of shower heads, hot water faucets and other demand points. The amount of hot water which these fixtures may be expected to draw is fairly well established and, as a matter of interest, is included in Table I. Of course, it is very unlikely that all of these fixtures would be in use at any one time so that after listing the fixtures and totaling the theoretical amount of hot water required, this total is reduced by applying a percentage "use" factor, also indicated in Table I, which has been proved by experience to be conservative. This then gives us a reasonably close approximation of the rate at which hot
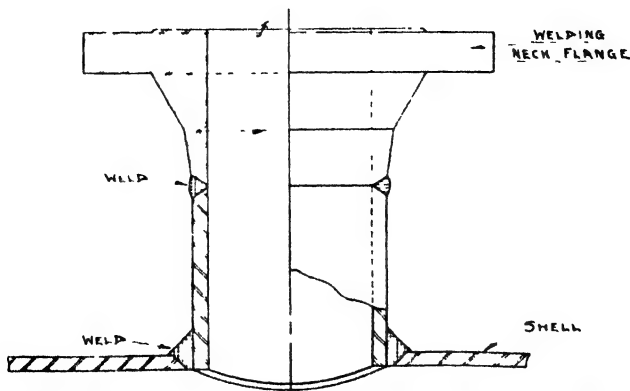
Fig. 2b. Typical welding details for flanged piping connection on storage heater.

water must be produced to satisfy the requirements, and knowing the steam pressure which will be used as a heating medium, the amount of heating surface and its proper arrangement to produce these results are readily determined by the designer.

The hot water storage capacity necessary to provide hot water at all times must also be determined. This involves a study of the sequence in use of the various fixtures and probable duration of use at any one time. In a large hotel, shower baths, for instance, may be taken by guests at any hour of the day or night, but this demand is not likely to be concentrated. On the other hand, in schools there is a rush for the showers at the end of each gymnasium period and the hot water storage must take care of this brief but heavy load. Experience has shown that by multiplying the hourly heating capacity previously determined by a factor which depends upon the type of building involved, a satisfactory storage capacity is determined. As an example, referring to Table I, supposing it is determined that the hot water fixtures of a large hotel indicate the use of hot water at the rate of 5000 gallons per hour. It is known from experience that these fixtures will not all be used all the time so we multiply by the "use" factor of 25 per cent. In other words, if the heater heats at the rate of 1250 gallons per hour, it will, in all probability, have ample heating capacity. The hot water storage capacity would then be 80 per cent of the hourly heating capacity or approximately 1000 gallons. This method of determining the amount of heating capacity and storage is, of course, approximate and, in general, conservative. The architect or engineer using this method must also temper his judgment with his own background of experience.

In textile mills, laundries, paper mills and other industries, it is frequently necessary to make a detailed survey before the requirements can be accurately determined. Sometimes it is necessary to install one or more water meters, preferably of the recording type, to determine the demand rate. This, in addition to a study of the sequence and duration of operations demanding hot water, usually provides the designer with enough information to proceed with confidence.

In view of the importance and widespread use of storage heaters, and the fact that one or more such heaters is in operation in practically every large building requiring hot water, the writer has elected to illustrate, in this paper, the changes and advantages of the welding of storage heaters as compared wtih riveted construction.

Storage Heaters—Storage heaters, as such, apparently made their appearance in the period of 1880 to 1890, and their use increased rapidly as their advantages became obvious. Riveted construction was considered the standard and preferred design until recent years. Early attempts to fabricate these heaters by welding were not too successful, due principally to the lack of any perfected welding technique. Furthermore, it was not realized that changes in design were necessary in some cases before a satisfactory welded job could be accomplished. As the result of inferior welding, welded heaters were quickly earmarked as inferior to riveted heaters, and the sales resistance toward welded heaters, not only on the part of the purchaser but on the part of the salesmen as well, was not overcome until the advent of a carefully planned procedure control, using welders regularly qualified in the prescribed manner.

Several weird designs appeared in the picture during the transition period between riveting and welding before a satisfactory welded heater was produced. An example of this was a combination of riveting and welding, in

Table I—Hot Water Fixture Capacity for Various Types of Buildings

Figure at a Final Temperature of 180 Degree F. Gallons of Water Per Hour Per Fixture

	Apartment House	Club	Gymnasium	Hospital	Hotel	Industrial Plant	Office Building	Public Bath	Private Residence	School	Y. M. C. A.
Basins, private lavatory	2	2	2	2	2	2	2	2	2	2	2
Basins, public lavatory	4	6	8	6	8	12	6	12		15	8
Bathtubs	20	20	30	20	20	30		45	20		30
Dishwashers	15	50–150		50–150	50–200	20–100			15	20–100	20–100
Foot basins	3	3	12	3	3	12			3	3	12
Kitchen sink	10	20		20	20	20			10	10	20
Laundry, stationary tubs	20	28		28	28				20		28
Pantry sink	5	10		10	10				5	10	10
Showers	75	150	225	75	75	225		225	75	225	225
Slop sink	20	20		20	30	20	15	15	15	20	20
Hourly heating capacity factor	30%	30%	40%	25%	25%	40%	30%	50%	30%	40%	40%
Storage capacity factor	125%	90%	100%	60%	80%	100%	200%	120%	70%	100%	100%

which the manufacturer first riveted the seams and afterwards fillet welded the edges of the longitudinal and girth seams. Needless to say, in welding the seams, the rivets loosened and leaked so that in order to make the shell tight, it was frequently necessary to deposit a bead of welding around many or all of the rivet heads.

Riveted Design—Fig. 1 illustrates a riveted type of storage heater. This heater consists, essentially, of a cylindrical shell enclosed at both ends acting as a water storage reservoir containing a steam actuated heating element located as low as possible. Steam admitted to the interior of the tubes heats the water contained in the shell. The shell is designed to withstand the normal pressure in the water mains to which it is connected and which is usually in the vicinity of 100 pounds per square inch gauge. The longitudinal seams are usually of the double riveted lap type in sizes up to 60 inches
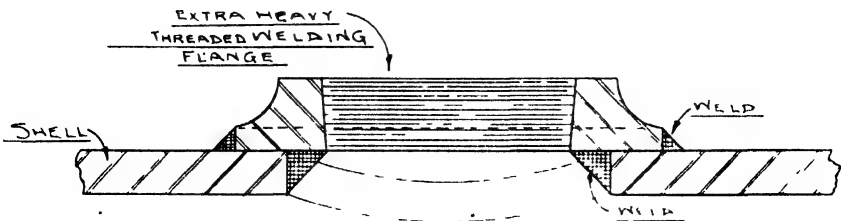
Fig. 2c. Typical welding details for screwed piping connection on storage heater.

in diameter. For larger diameters, they may be triple riveted lap, double riveted, double butt, or triple riveted, double butt, depending upon the diameter, working pressure and efficiency of seam required. The girth seams are usually single riveted lap. A manhole, of the integral flanged type, 11 inches x 15 inches, with yoke and cover, is incorporated to provide access to the interior in all but the smaller sizes. Piping connections for water inlet, outlet, drain and miscellaneous connections are castings or forgings riveted in place. The port to which the heating element is attached is a casting riveted to one of the concave heads or to the side of the shell in vertical heaters.

Stocking plates and heads for the immediate production of storage heaters after receipt of orders is simplified by adhering, as far as possible to a set of standard shell diameters and lengths. A list of our standard sizes of storage heater shells is given in Table II. Special sizes are frequently manufactured to order when limitations of space prevent the installation of a standard size.

It should be noted that the headport to which the tube sheet and steam distributing head are bolted is a casting, for which a pattern is required. Since there are many combinations of heating capacity, storage capacity and design pressure, and since these castings must fit the contour of the flanged and dished heads of horizontal heaters or the shells of vertical heaters, the initial cost and maintenance of pattern equipment is a substantial item.

Welded Design—Storage heaters are unfired pressure vessels and, as such, must be designed and fabricated in accordance with existing safety regulations provided by the laws of the state or municipality in which the installation is to be made. Rules covering the construction of unfired pressure vessels have been worked out in detail by the American Society of Mechanical Engineers and are presented in Sections 8 and 9 of the A.S.M.E.

Table II—Storage Capacity and Over-All Dimensions of Standard Sizes of Shells for Storage Heaters

Storage Capacity in Gallons	Shell Dia. Inches	Length O.A. (Inches)	Weight (Pounds)
60	18	60	400
75	18	72	450
110	24	60	600
130	24	72	700
150	24	84	800
170	30	60	750
200	30	72	850
240	30	84	950
280	30	96	1050
340	36	84	1300
400	36	96	1450
450	36	108	1600
500	36	120	1800
530	42	96	1850
680	42	120	2150
800	42	144	2500
970	42	168	2900
870	48	120	2850
1050	48	144	3250
1250	48	168	3700
1400	48	192	4100
1100	54	120	3250
1300	54	144	3700
1500	54	168	4200
1800	54	192	4700
1300	60	120	4300
1600	60	144	4900
1900	60	168	5600
2200	60	192	6200
2300	72	144	6500
2700	72	168	7300
3100	72	192	8100
3700	84	168	8800
4300	84	192	9700
4900	84	216	10,600
5500	96	192	12,500
6300	96	216	13,800
7000	96	240	15,000
7800	96	264	16,200
9050	108	240	18,700
10,000	108	264	20,200

Code for Unfired Pressure Vessels. These rules specify, in detail, the procedure by means of which welders may be qualified for welding unfired pressure vessels and the materials which may be used in their construction. The materials are specifically identified by reference to corresponding A. S. T. M. Specifications where applicable.

When designed and manufactured in accordance with the requirements of the A. S. M. E. Code and so stamped, the pressure vessel is acceptable for insurance purposes. Several states and a number of municipalities have adopted the A.S.M.E. Code and pressure vessels coming within the scope of the Code must be designed and manufactured in accordance with the provisions contained therein before acceptance.

Since the details involved in selection of materials to the proper specifications, the preparation and shaping of parts to be welded, and the proper procedure control of welders are all fully outlined in the A.S.M.E. Code and
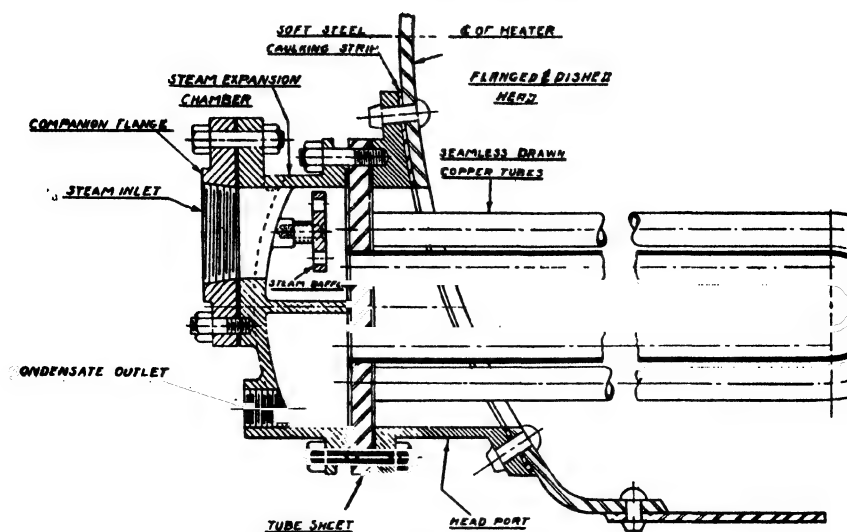
Fig. 3. Detail of riveted head port nozzle.

are, therefore, matters of common knowledge, it is unnecessary, for the purpose of this paper, to go into this phase of the subject in greater detail. As a matter of interest, however, a number of typical welding details are included in Fig. 2a, 2b and 2c. It should be added that all welding used in the construction of these storage heaters is shielded arc, using a cellulose coated rod.

Of special interest in the construction of these heaters is the port in which the heating element is installed. Formerly, this was an iron casting riveted in place, as shown in Fig. 3. Before it could be satisfactorily welded, however, the design had to be very substantially changed. The details of the port as redesigned are outlined in Fig. 4. The cylindrical portion consists, in the smaller sizes, of a short length of steel pipe. In larger sizes, it is more economical to roll up a piece of steel plate with a butt welded longitudinal seam. By making the cylinder of the necessary thickness and allowing it to protrude inside the flanged and dished head, sufficient reinforcement is provided to compensate for the metal removed in cutting out the section of the head to permit passage of the heating element. The bolting flange, to which the tube sheet and steam chamber are bolted, may be fabricated either by Van Stoning the end of the cylinder and providing a suitable backing up flange, or by welding on a steel plate flange, or by butt welding on a welding neck type of flange. The welding neck flange is preferred since only a simple butt weld is required to attach it to the cylindrical part of the port, but the cost of the welding neck flange itself is considerably greater than that of a steel plate flange.

Recently, the writer developed a method of producing welding neck flanges to meet our storage heater requirements by fabricating them from bar stock. These rectangular bars, of the proper cross section, are scarfed and butt welded end to end to form a continuous length of 60 to 100 feet, depending upon the size of bars and total weight involved. The bar is then drawn slowly through a gas furnace, where it is heated to about 1500 degree F.

and immediately coiled on a standard pipe bending machine in a spiral coil to approximately the required diameter. While still hot, each complete circle is torch cut and flattened. The ends are scarfed with a torch and butt welded. A few minutes machining on a vertical turret lathe and the welding neck flange is complete, ready for drilling the bolt circle. Since only a relatively few sizes are involved and the requirements in each size are fairly large, by taking advantage of quantity production, we are able to produce these flanges for substantially less than the cost of forged steel flanges purchased in the open market, with the added advantage that they can be manufactured for stock at our convenience, utilizing our own labor and equipment. They are also used as bolting flanges, for other types of heat exchangers, which increases their use considerably.

We have also recently adopted the practice of welding in the manhole frames instead of having them flanged integrally with the head at the mills. It was previously our standard practice to stock plain flanged and dished heads for one end of each different shell size and a corresponding number of heads with integrally flanged manhole frames, as shown in Fig. 5, for the other end. By welding in the manhole frame, as indicated in Fig. 6, we are able to substantially increase the flexibility of our stock, by stocking plain, flanged and dished heads only. The collar forming the gasket surface for the manhole cover is made amply strong to provide the necessary reinforcement to compensate for the metal removed from the head and fully complies with the requirements of the A.S.M.E. Code.

Other Advantages of Welding—It is a well known fact that water at a low temperature can hold more oxygen in suspension than water at a higher temperature. Therefore, water saturated with oxygen at its normal ground temperature is forced to release it as its temperature is raised. At 212 degree F. it is nearly all released. In storage heaters, the usual practice is to heat
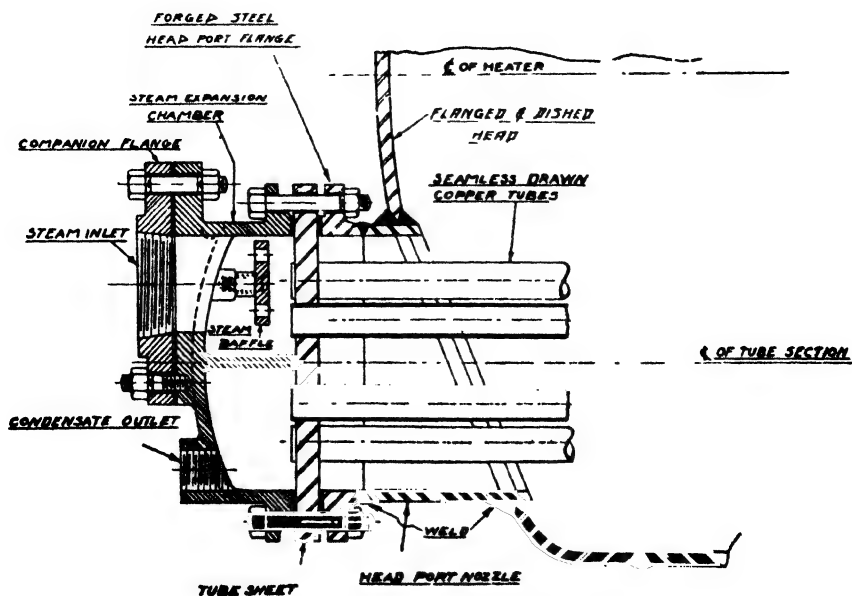
Fig. 4. Detail of welded head port nozzle.
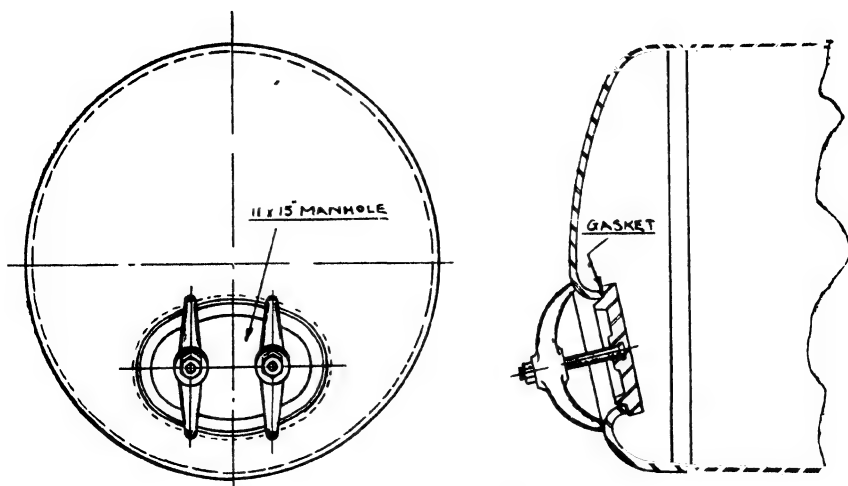
Fig. 5. Detail of manhole frame.

water from the ground or tap water temperature, which is usually in the range of 40 degree to 70 degree F., up to a final temperature of 180 degree F The temperature is controlled at 180 degree F. by means of a temperature regulator which automatically shuts off the steam when the desired water temperature is reached. It is clear, therefore, that in heating water through a temperature range of over 100 degree F., a considerable percentage of the entrained oxygen is released. This released oxygen immediately tends to react on the interior surfaces of a heater with steel shell, producing iron oxide or rust. This condition is undesirable for two reasons. First, because the corrosion, once started, usually continues until a point is reached where the shell must be replaced. Second, rusty water is a very great nuisance and considerable labor is frequently required in cleaning the heaters periodically to keep the water as clean as possible. Some grades of water are more corrosive than others, but in many cases water contains scale-forming elements which are precipitated on the steel surface as the temperature is raised, thus forming a protective coating over the steel and substantially reducing the rate of corrosion.

In answer to a demand for storage heaters in which the rusty water nuisance is eliminated, rust resisting enamels of many different makes have been tried, both experimentally in the laboratory and under actual service conditions. Few of them will stand up for any length of time, and even the most resistant ones usually have to be renewed every few months to give adequate protection. Galvanizing and other corrosion retardents have been used with more or less success.

Since, in many processes requiring hot water, even small quantities of iron cannot be tolerated, the preferred solution in such cases is a design in which the water comes in contact with nothing but non-ferrous metals in passing through the heater. Thus, many storage heaters are built with steel shells lined throughout with copper or other non-corrosive metals. Though it is not impossible to line the interior of a riveted shell, the designer has to contend with rivet heads and butt strap joints. The problem is greatly simplified in a welded shell using butt welded seams which produce a smooth interior.

Storage heaters are also manufactured from steels clad on one side with non-corrosive metals such as stainless steel or nickel. Welding much simplifies the manufacturing of such materials. Using butt welded seams, the abutting steel parts of the plates are electric arc welded, using a cellulose coated steel rod, while the abutting clad portions of the bi-metal plates are welded with a rod of the same material as the cladding. Thus, the interior of the heater may be entirely stainless steel when fabricated from stainless clad steel plates or entirely nickel when using nickel clad steel plates. The use of bi-metal plates rather than solid stainless steel or nickel has the advantage of lower cost.

Storage heater shells constructed entirely of copper silicon alloy plates are also found very satisfactory in combating corrosion. This alloy, consisting of approximately 95 per cent copper and 5 per cent silicon, has a tensile strength closely approaching that of mild steel and corrosion resisting properties similar to those of copper. Riveting shells constructed of this material has not proved too satisfactory since the alloy has a relatively low yield point and there is a tendency for the rivet holes to pull out of shape during the hydrostatic testing of the completed heater. Excellent results, however, are produced by welding.

Comparative Cost Data—In setting up comparative costs of riveted versus welded heaters, the comparison should be made on the basis of storage heaters in which the shells are manufactured from steel rather than from some of the materials previously described, since the number of steel shell storage heaters being manufactured is much greater than those constructed of other materials. A clear picture in regard to what welding has done to reduce the cost of manufacturing is obtained by comparing the complete cost of a riveted heater with the complete cost of a welded heater rather than comparing costs of the component parts.

The cost comparison has been set up for a medium sized heater with a shell diameter of 48 inches and an over-all length, face to face of flanged and dished heads, of 144 inches. The thickness of shell plates is ⅜-inch and thickness of the heads ½-inch. In each case, the material, both for shell plate and heads, conforms with A.S.M.E. Code Specifications S-1 and
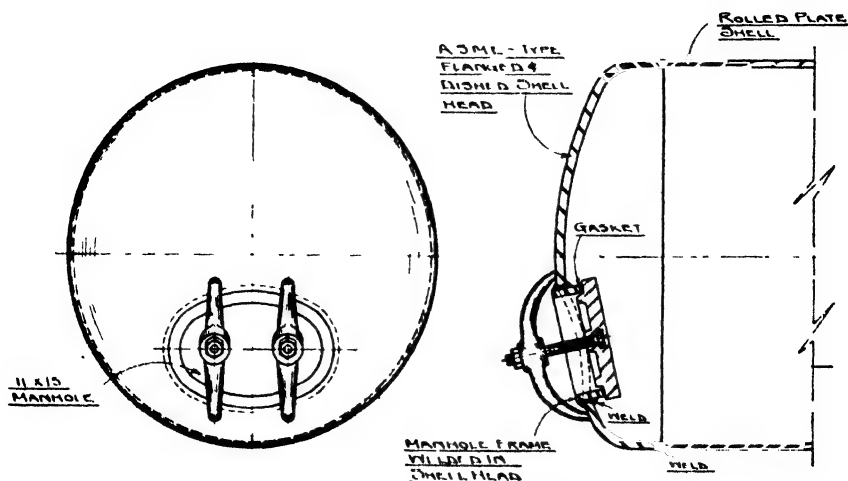
Fig. 6. Welded manhole frame.

A.S.T.M. Specification A-70, latest edition. The cost of the heating element, consisting of tubes and tube sheet assembly, steam distributing head, bolts, nuts and gaskets are the same for either riveted or welded designs. Therefore, these items are omitted from the comparison.

The cost of maintenance of factory equipment, power and overhead are practically the same for either riveted or welded construction. The percentage difference in cost of sizes other than the one upon which the cost comparison was made will depend upon several factors, such as the number of shell plate courses, size of port for heating element, etc., but the above may be considered as a fair indication of the average percentage reduction for all sizes as listed in Table II.

Figures relating to the average number of storage heaters manufactured yearly are not available to the writer. It is estimated, however, that the figure runs into several thousands, of which this company manufactures a substantial percentage.

Riveted Steel Shell

	Weight	Cost
2—Main Shell Plates, 3/8″ thick	2248 lbs.	$56.40
1—48″O.D. × 1/2″ thick Flanged and Dished Head (Plain)	375	20.89
1—48″O.D. × 1/2″ thick Flanged and Dished Head with 11″ × 15″ Integral Manhole Frame	360	28.11
1—11″ × 15″ Manhole Cover complete	40	6.00
4—4″ Riveted Type Nozzle Flanges 1—1 1/4″ " " " Flange 1—1″ " " " " 1—3/4″ " " " "	70	9.73
1—Cast Iron Headport Nozzle	125	10.30
Rivets	180	9.00
	3398 lbs.	$140.43

Direct Labor

Lay out, shear, plane & roll	$5.60
Punch rivet holes	9.40
Assemble for riveting	5.40
Rivet & caulk	21.70
Machine headport nozzle	5.40
Hydrostatic test	2.90
	$50.40

Total cost of raw materials	$140.43
" " " direct labor	50.40
Total material & direct labor	$190.83

Note:—The cost of raw materials is based on purchasing those which are subject to quantity discounts in sufficient quantity for the production of twenty-five heaters. Direct labor cost records are kept continually by the Company, and those included in the above comparative cost analysis were derived from this source.

Welded Steel Shell

	Weight	Cost
2—Main Shell Plates, 3/8" thick	2144 lbs.	$53.85
2—48"O.D. × 1/2" thick Flanged and Dished Heads (Plain)	725	41.78
1—3/4" × 3" × 48" Steel Plate for Manhole Frame	30	.76
1—11" × 15" Manhole Cover complete	40	6.00
4—4" Welding Spuds; 1—1 1/4" " Spud; 1—1" " "; 1—3/4" " "	35	4.92
1—3/8" × 14" × 48" Steel Plate for Headport Nozzle	71	1.78
1—2 1/4" × 2 1/4" × 56" Steel Bar for fabrication of Headport Welding Neck Flange	80	3.20
Cellulose Coated Welding Rod	35	2.27
	3160 lbs.	$114.56

Direct Labor

Lay out, shear, plane & roll	$5.36
Assemble for welding	5.40
Weld & chip	18.22
Fabricate & weld manhole frame	2.25
Cut, roll & machine headport nozzle	3.80
Hydrostatic test	1.50
	$36.53

Total cost of raw materials	$114.56
" " " direct labor	36.53
Total material & direct labor	$151.09
Cost of Raw Materials & Direct Labor—Riveted	$190.83
" " " " " " " —Welded	151.09
Reduction in Cost in Favor of Welded Design	$39.74

Percentage Reduction in Cost = 20.8%.

Weight of Raw Materials Used in Riveted Design	3398 lbs.
" " " " " " Welded "	3160
Reduction in Weight in Favor of Welded Design	238 lbs.

Percentage Reduction in Weight = 7%.

Cost of Direct Labor — Riveted Design	$50.40
" " " " — Welded "	36.53
Reduction Direct Labor Cost	$13.87

Percentage Reduction in Cost = 27 1/2%.

Fig. 7. A complete welded storage water heater.

Social Advantages—Hand riveting and caulking operations are extremely noisy. One has only to spend a few minutes near an operator caulking a riveted seam inside a closed building to be convinced of this. If the only social advantage gained by the change from riveting to welding was the elimination in the factory of the noise nuisance from this source, the change was worth while. But if riveting produces a noise nuisance in a factory where other noisy operations are in progress, the nuisance is many times amplified in a relatively quiet hotel, school or hospital when repairs become necessary.

Welded heaters, Fig. 7, have not been in service nearly as long as many of the original riveted heaters so that it is perhaps unfair to say that welded heaters will outlast riveted ones of the same grade and thickness of materials. However, it seems a reasonable assumption that as the shell plates of riveted heaters thin down by the corrosive action of the water being heated therein, the difficulty of keeping riveted seams and rivet heads tight will increase with the age of the heater until it is replaced, as it inevitably will be, by one of welded construction. It should also be added that heaters properly designed for the conditions under which they are to operate, and welded by experienced and properly qualified welders, are practically trouble free in service and require no noisy and expensive repairs.

Finally, the saving of approximately 7 per cent by weight of materials which are of strategic importance to the United States, and the saving in labor of approximately 27½ per cent, is worth while at any time, but under the present National Emergency, when every effort is being strained to produce more goods in a shorter period of time, the saving in time and materials by welding is particularly desirable.

Chapter III—The Drumless Boiler

By Robert E. Moyer, Jr.,

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Robert E. Moyer, Jr.

Subject Matter: The drumless boiler for high pressure steam generation. All headers and tubes are less than 18 inches in diameter and details of boiler construction are shown in photostat figures. All welding is either fillet or circumferential by a qualified welder. Header X-rayed only if exposed to heated gases and stress relieved and tested to twice generating pressure or operating pressure. This design is submitted by the author with the approval of the inventor of the drumless boiler, John Phillips Badenhausen, M.E., M.M., Philadelphia, Pa.

The scientific research of arc welding, coordinated with the other types of design and the adoption to practical applications perfected with X-ray, permits the boiler shop operator who was always limited in his manufacturing capacity, to build power plant boilers, superheaters, economizers and airheaters in his small plant. This modern possibility and development is accomplished by arc welding and arc welding design.

The power plant boiler which this idea and accomplishment refers to is not the low-pressure boiler, but boilers which will operate at a pressure range of 600 pounds per square inch and upward to 2,500 pounds per square inch pressure, with a steam generating capacity of 300 pounds per hour to 500,000 pounds per hour or more, fired with pulverized coal, oil, waste heat gases, coal fired stokers or natural gas.

The superheater, economizer, airheater boiler casing is constructed by welding, either in the shop or at the site of erection, depending upon the size of the unit handled.

The company with which the writer is associated recently completed eight water tube boilers, each having a capacity of 36,000 pounds of steam per hour, designed for an operating pressure of 200 pounds per square inch, but this is not the type of compact design this paper refers to because these boilers were made with boiler drums.

The Drumless Boiler—The drumless boiler, (See Figs. 1 and 2), could not be built without welding for the high pressures which are demanded by industry. It would be very poor engineering to rivet steel or alloy metals two inches thick or four inches thick where high heat and temperature would cause fire cracks and other types of failures common to the power plant boilers, even at thicknesses of less than one inch. This, the common failure, is very unlikely in the drumless boiler because there is no large boiler drum.

The boiler manufacturer can build these new boilers with less shop machinery and compete with the largest boiler manufacturer in business today. The plate rolls, the press, the mammoth planer, that were required
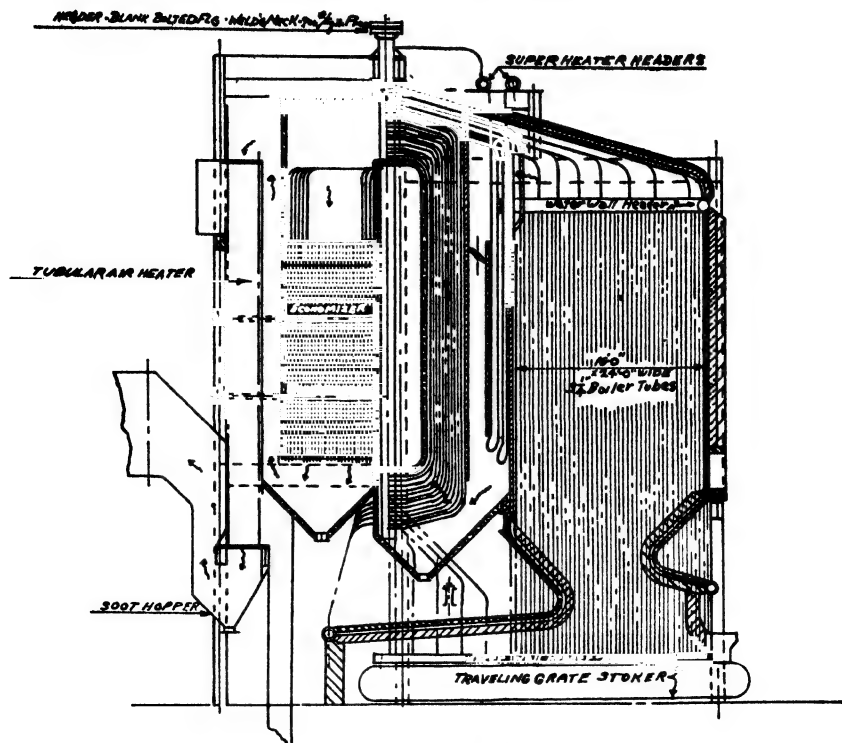
Fig. 1. Sectional side elevation.

and restricted the small boiler shop and limited the field of competition. These costly tools or machines create large plant overhead, raise the selling price of the product and they are not now the essential machinery.

The drumless boiler has many other important features; namely, this boiler requires less steel to build, in several instances one third of the steel by weight was saved, yet the boiler capacity remained the same in pounds of steam generated per hour. The labor hours to manufacture this drumless boiler in all cases were estimated and were found to be 20 to 30 per cent less for the same capacity boiler. The time for field erecting in labor hours and field time were greatly reduced because of the design and it simplified erection.

The designer of this new drumless boiler is an engineer who has designed over 500 large-size power plants. One plant operated at 86 per cent efficiency and was of water tube design. One of the drumless boilers is now under construction and will operate at 800 pounds working pressure.

The photostats, Figs. 1 and 2, of the small boiler and the large boiler are included to show the new drumless boiler with the simplified construction.

This design could be adapted in the naval field because of the high pressure. With reduced weight, the fast steaming features our boats or ship cargos could be greatly increased without sacrificing steam generating ability and capacity.

The A.S.M.E. boiler code committee has thoroughly covered the subject of boiler construction and the drumless boiler we are manufacturing has been approved by the Hartford Steam Boiler Inspection and Insurance Company
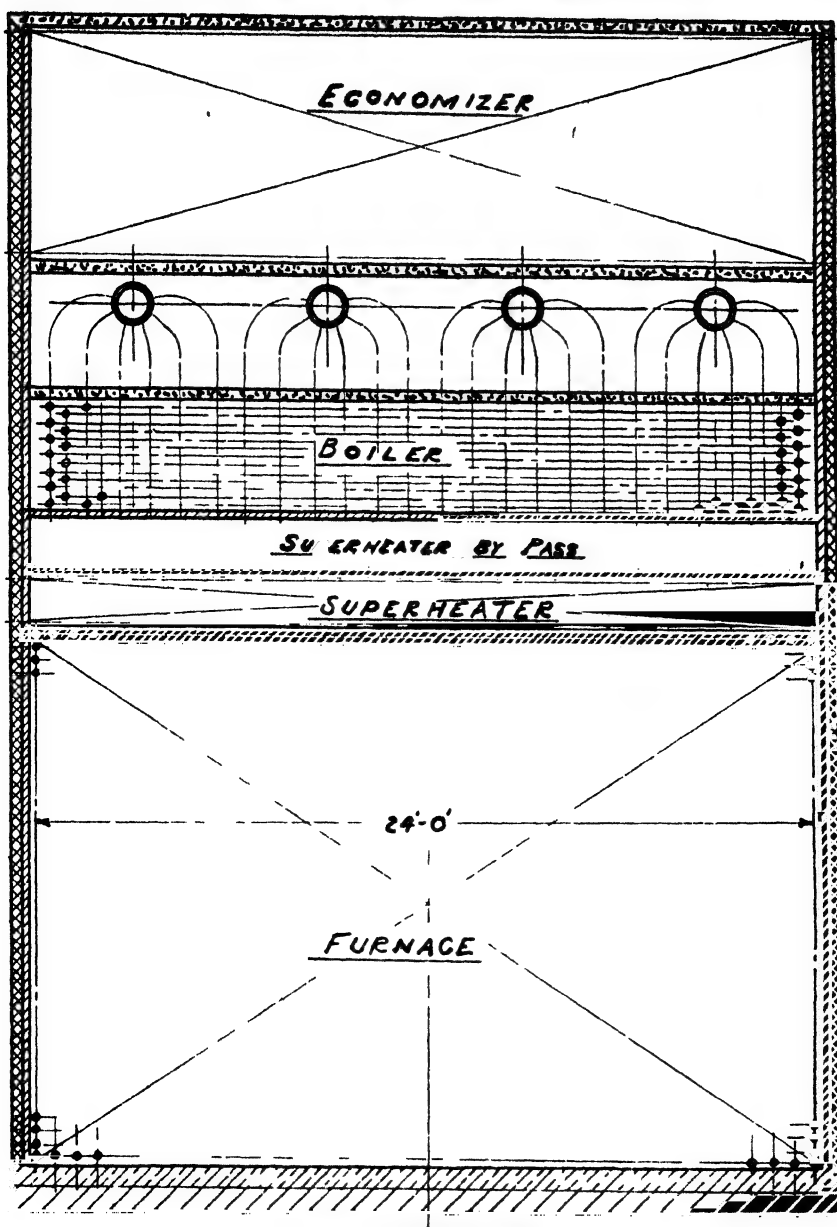
Fig. 2. Sectional plate.

which definitely establishes the drumless boiler as practical from a manufacturing standpoint as well as design.

The boiler code committee states that tubes 18 inches in diameter and less shall be called tubes or headers and because no tube or part of the drumless boiler is greater than the established diameter of 18 inches, the boiler contains no drum.

The drumless boiler has no longitudinal joints to fabricate, therefore, no planer is required.

The headers are constructed of high-pressure tubing purchased as tubing or pipe, therefore, no heavy plate rolls or press are required for fabrication. All the arc welding on this boiler is either filet or circumferential welding. The one end of the header is closed by inserting a blank plate inside the header and is arc welded in accordance with the welding procedure established by qualification and test. The top part of the header is closed by attaching a welding neck of flanged type with bolted blank flange. The key-cap, master holes and hand holes are drilled and back cut to suit the requirements that any manufacturer adapts to his facilities. The tube holes are drilled and grooved, ready for tube insertion and expanding or welding. This header is X-rayed only if the part welded is exposed to the heated gases at high pressures. This we know will establish the appearance of the test plate and the quality of the welder for tensile, bending, elasticity, etc. Before drilling or putting any holes in the header, it must be stress relieved and then tested to twice the working pressure or operating pressure.

The header is now completed and the most difficult part of the job is accomplished. Because the water wall headers are smaller and the superheater header or headers are fabricated like the main boiler header, only a blank plate is used to close both ends.

The boiler tubes in the side wall or water walls (circulator tubes and tubes in the various passes are usually selected for the conditions in the boiler) are considered to be three and one-quarter inches in diameter, superheater tubes two inches in diameter and economizer tubes two inches in diameter. The tubes are bent to suit the location that they are to be used for integral connection.

Another feature of the drumless boiler is the fact that each main header and the tube arrangement connecting the header can be shop fabricated as a complete element and can be shipped as an assembled unit, the entire unit weighing less than an old style boiler drum that would be made of two- or three-inch thick steel, depending on the designed pressure.

A boiler to equal the one shown on the photostat with a marking of 125,000 pounds would be made with two or three drums, one 60 inches in diameter, two or three inches thick and 26 feet long; another about 48 inches in diameter, length the same, thickness the same, the thickness being controlled by the operating pressure. If this type of boiler was to operate at 1500 or 2000 pounds per square inch, you can appreciate the weight of this method against the drumless boiler method.

The advantages accomplished by arc welding co-ordinated with designs, are as follows:

1, Save steel for our nation now at war, in large quantities, instead of trying to accumulate tons by saving hair pins, paper clips and razor blades.

2, Build more boilers in any boiler shop. Heat treating and X-raying can be sublet if the shop that wants to make this work lacks this equipment.

3, Produce better and higher pressure boilers for land and naval use at less cost to the national government.

4, Increase our cargo capacity on our ships, or reduce the ship space, adding larger guns and carry more ammunition or food to our allies.

5, Make boilers of higher pressures easier, simpler and faster.

Chapter IV—Arc Welded Power Penstocks

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Subject Matter: Progress in the application of arc welding on penstocks. The penstocks described are considered to be the first of such diameter with all joints double butt welded and radiographed, with every 20 foot section stressrelieved, and hydrostatically tested. The proportionate cost saving in percentage is 41 per cent and the annual gross savings in an average year's construction program of the Bureau of Reclamation are estimated at approximately $920,000. The social advantages include a fuller protection of life and property.

The continuous improvements made during recent years in the art of fusion welding are responsible for a radical change in the joining and fabrication of steel structures. Riveted construction gradually gave way to welded construction until in some lines of work such as pressure vessels and water conduits riveting is rarely used today. The successful shopwelding of the huge Boulder Dam penstocks furnished the best proof that arc welding is fully reliable and economically sound. Further improvements made in welding procedures since that time demonstrated the superiority of the arc welding process over riveted construction especially in the construction of conduits subjected to high heads where a smooth flow line and a conservation of head and power is required. The high head penstocks at Shasta Dam on the Central Valley Project, in California, constitute a further important progress in the application of arc welding on pressure conduits. These penstocks are considered to be the first of such diameter and plate thickness with all joints double butt welded, and radiographed, with every 20 foot pipe section stress-relieved and hydrostatically tested and with the entire installation to be subjected to a hydrostatic pressure test equal to 150 per cent of the operating pressure to prove its safety under the most severe service conditions.

Before arc welding proved its superiority, riveted joints were used for pressure conduits operating under various heads. For low head installations often woodstave pipe was used and for smaller pipe operated under very high heads hammer forge-welded or banded pipe was used. In recent years reinforced concrete construction is sometimes used for low and medium head pipe lines when conditions are favorable for such installation. The high head under which many water conduits are to be operated precludes the use of reinforced concrete construction, as concrete although heavily reinforced with circumferential hoop steel cannot be prevented from extensive cracking with resultant leakage and deterioration under such pressure. In addition, concrete not having the resiliency of steel could not absorb the heavy surges and water hammer shocks which occur in penstocks due to

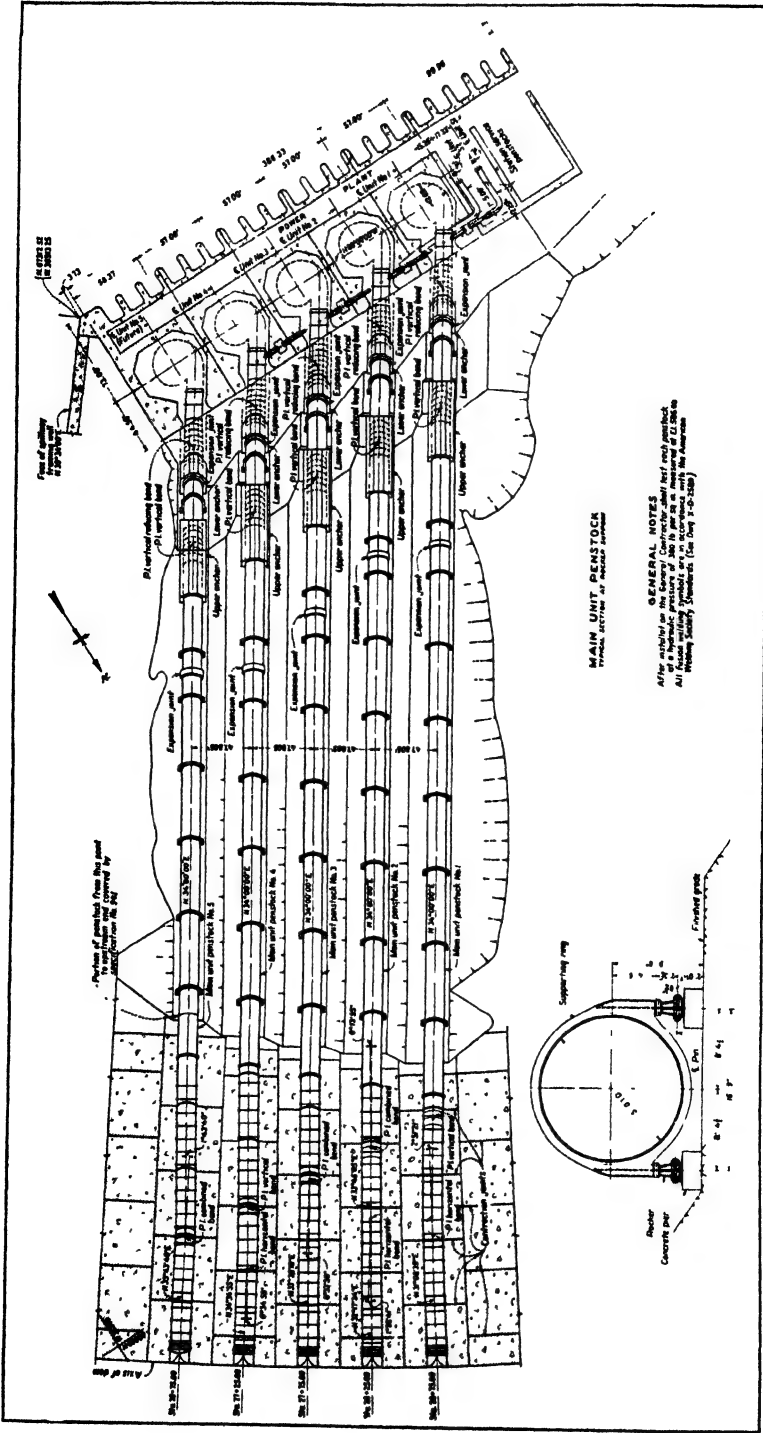
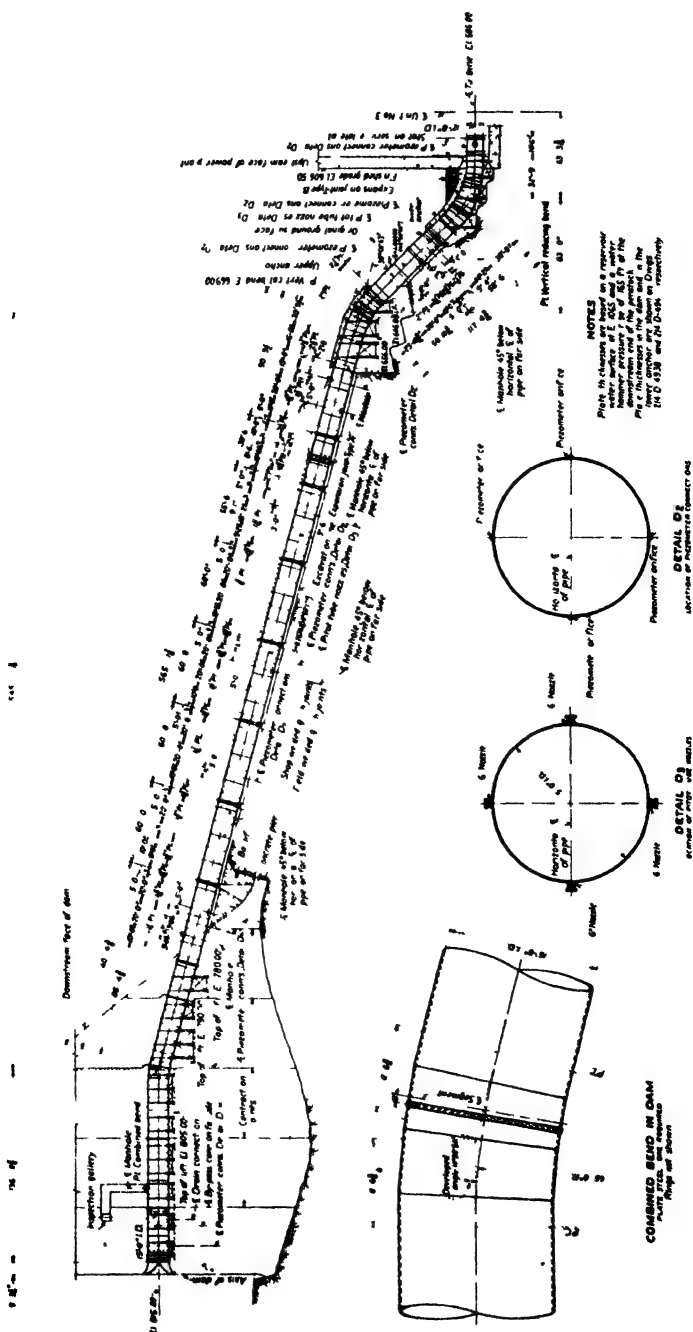



Fig. 1. General plan Shasta Dam penstock.

Fig. 2. Profile of penstock No. 3.

turbine gate closure or in pump discharge lines due to reversal of the water column when the pump stops because of power failure.

The Shasta penstocks no doubt represent the most advanced type of full-welded pressure conduits. Their design combines a number of favorable features to assure the ultimate in structural safety and hydraulic efficiency which can only be achieved with arc welded construction. In the following paragraphs the pertinent features of the design and construction will be briefly sketched.

Design of Penstocks—The Shasta penstocks will serve five turbines each having an output of 103,000 horsepower at 330 feet of head and full gate corresponding to a full generator rating of 75,000 kilowatts at unity power factor. The units will be operated under a minimum head of 238 feet and a maximum head of 475 feet. The penstocks are 15 feet in diameter starting with a concrete bellmouth entrance at elevation 815 at the axis of the dam, then running radially through the dam at that elevation to a bend from which they proceed at an angle of from 14 to 16 degrees to a second bend enclosed in the upper anchor, following which they continue on a slope of 45 degrees to a third bend enclosed in the lower anchor where they level off to the turbine inlet at elevation 586, as shown in Figs. 1 and 2.

The penstocks are protected at the bends, with massive reinforced concrete anchors and are provided with expansion joints for each tangent to permit free temperature movements in the pipe line. The upper ends are embedded in the dam concrete and below the dam the penstocks are supported on heavy cast steel rockers as shown in Fig. 3, which are grouted into reinforced concrete piers and set in accordance with the prevailing temperature. The supports are spaced at 60-foot centers and closer at the expansion joints.

The pipe shell is stiffened at the points of support with double ring girders provided with supporting brackets over the rockers, as shown in Fig. 4. These ring girders will prevent deformations in the shell due to the pipe and water loads, concentrated at the supports. All bends are designed with long radii and small deflection angles as shown in Figs. 5 and 6, for improved hydraulic efficiency. The upstream embedded pipe and the bend sections are provided with temporary structural steel supports for use during installation and concreting. The expansion joints are shown in Fig. 7 and are of the stuffing-box type, machined to provide a close fit between moving parts. A brass seat ring is placed at the base of the stuffing box to retain the nine rings of 1¼-inch square lubricated flax packing compressed by the packing gland. The inner expansion sleeve is provided with a 3½ per cent nickel-clad surface to prevent its corrosion and sticking to the packing gland. Both expansion sleeves are made from extra heavy steel plate, the outer sleeve being also reinforced with two stiffeners to prevent its deformation and improve the water tightness of the joint. The packing can be uniformly compressed with eighty 1-inch studs in the gland.

The five penstocks vary in length from 798 feet to 931 feet, and are made accessible with 20 inch diameter manholes located at 45 degrees from the invert. The upstream ends are protected with temporary dished bulkheads for protection against high water during construction. The penstocks are designed for a maximum static head of 479 feet plus a maximum water hammer head of 180 feet based on a minimum turbine gate closure of 4-seconds for a full gate-opening or full gate-closing stroke. The embedded pipe was designed to carry the total head (static and water-hammer) at a hoop stress equal to two-thirds of the yield point of the steel plate, the

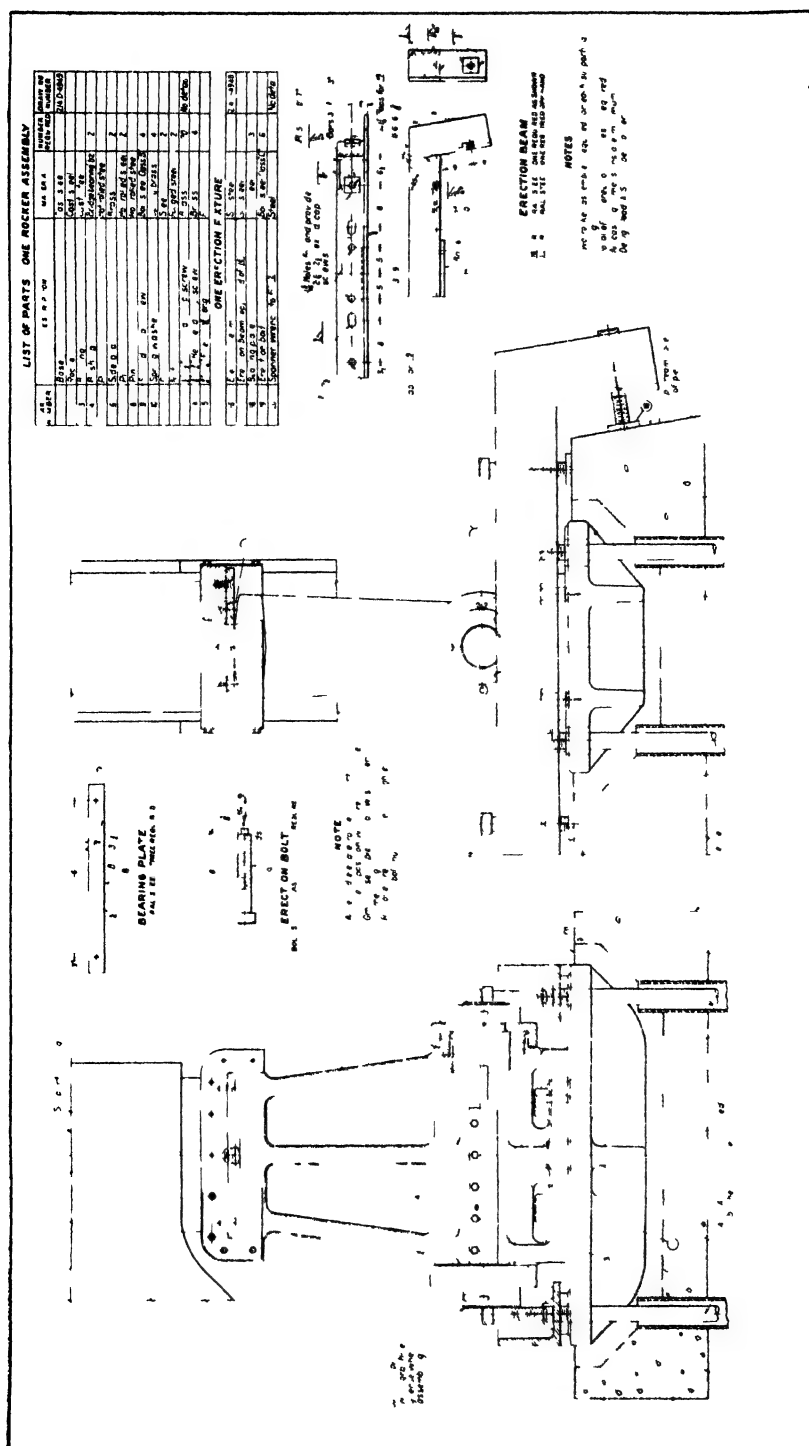



Fig. 3. Rocker support assembly.

pipe below the dam was designed to carry the total head at a combined stress equal to one-half of the yield point of the steel. The specifications provided that all butt-welded joints in the shell are to be radiographed, further that all pipe sections shall be stress-relieved and hydrostatically tested at a hoop stress of 22,000 pounds per square inch, to prove the safety of the pipe.

This fabrication procedure permitted the use of a joint efficiency of 95 per cent, in accordance with the A. P. I.-A. S. M. E. code for unfired fusion-welded pressure vessels. The computed shell thicknesses vary from ¾-inch at the upstream end to 2⅜-inches at the lower end. All joints in the pipe shell are double butt-welded, except the field girth joints opposite the contraction joints in the dam. These joints are provided with outside buttstraps welded to the pipe at the upstream edge. The butt-joint in the pipe shell will remain un-welded until after the concrete in the dam has cooled off and the contraction joints are grouted tight. After the grouting is completed the slip-joints will be welded up from the inside of the penstocks. The outside of these slip-joints are protected with asbestos sheet packing, extending for 5 feet at each side of the joint, to prevent a bond between the steel pipe and concrete, reducing thereby the fixity of the pipe and a tendency of cracking in the weld. Each penstock is provided with a by-pass and drain connection near the upstream end, for filling and drainage purposes, also with piezometer and pitot tube connections for pressure and velocity determinations in connection with the turbine performance tests. At the downstream end each penstock except No. 5 is provided with a lateral for connection of 36-inch diameter penstocks leading to two 3500 horsepower station service turbines connected to 2500 kilowatt generators.

Steel Plates—The steel plates used are of the firebox quality, grade B, in accordance with the standard specifications for low tensile strength carbon steel plates, A. S. T. M. designation A-89, of the American Society for Testing Materials. Tests were made of every heat of steel at the mill, twenty-one of which, including thicknesses from 1 inch to 2½ inches, showed the following range in physical and chemical properties:

	Range	
Yield point	28,560 to 43,200 p. s. i.	(average 33,000)
Tensile strength	55,160 to 61,950 p. s. i.	(" 58,000)
Elongation in 8-inches	25 to 37%	(" 30)
Carbon	.14 to .22%	(average .17)
Manganese	.43 to .58%	(" .50)
Silicon	.08 to .10%	(" .09)
Phosphorus	.010 to .016%	(" .012)
Sulphur	.024 to .039%	(" .032)

The above physical values compare with the following specification requirements: a minimum yield point of 27,000 pounds per square inch, an ultimate strength of 50,000 pounds per square inch and an elongation in 8-inches $\frac{1,550,000}{\text{Tensile strength}}$. The low carbon content with its low air-hardening properties makes it possible to produce ductile welds with the use of heavily coated electrodes, which will be able to withstand the surges and shocks, due to water hammer in the pipe line. This is extremely important in penstocks and pump discharge lines where brittle welds may develop cracks and ruptures in the line causing interruptions in service and often extensive damage in life and property. The stress-relieving of completed sections will further improve the ductility of the deposited weld metal and

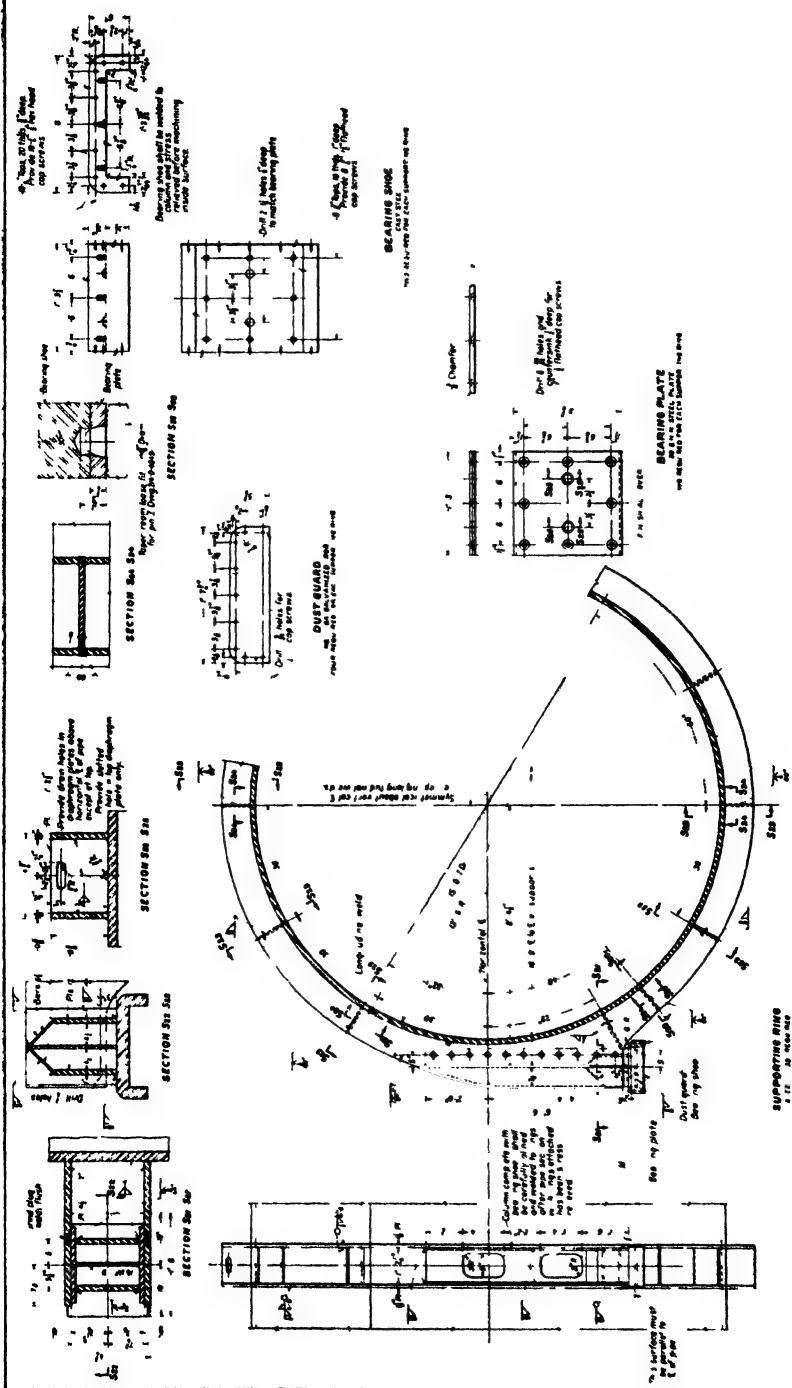



Fig. 4. Supporting ring.

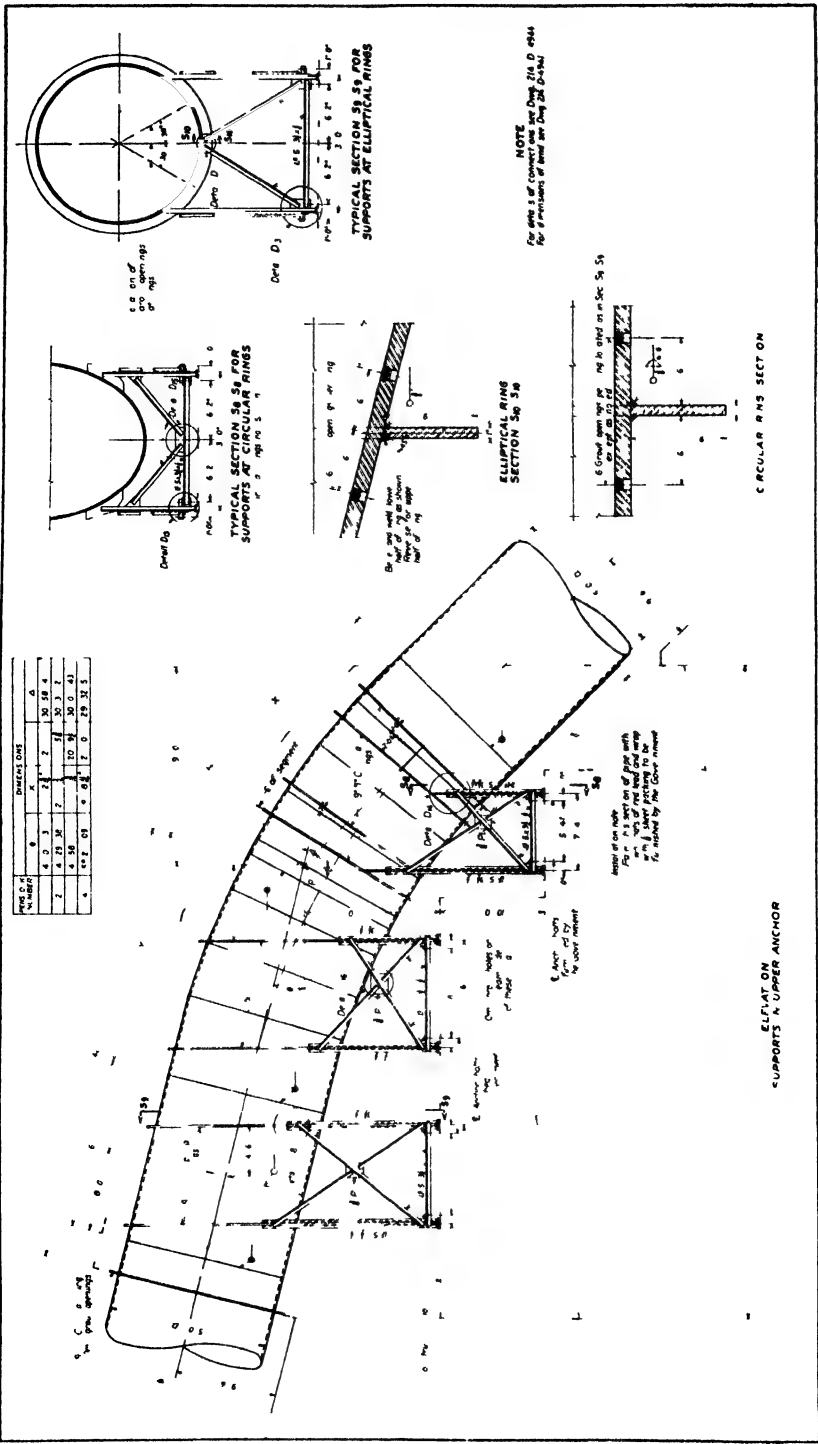



Fig. 5. Supports in upper anchor.

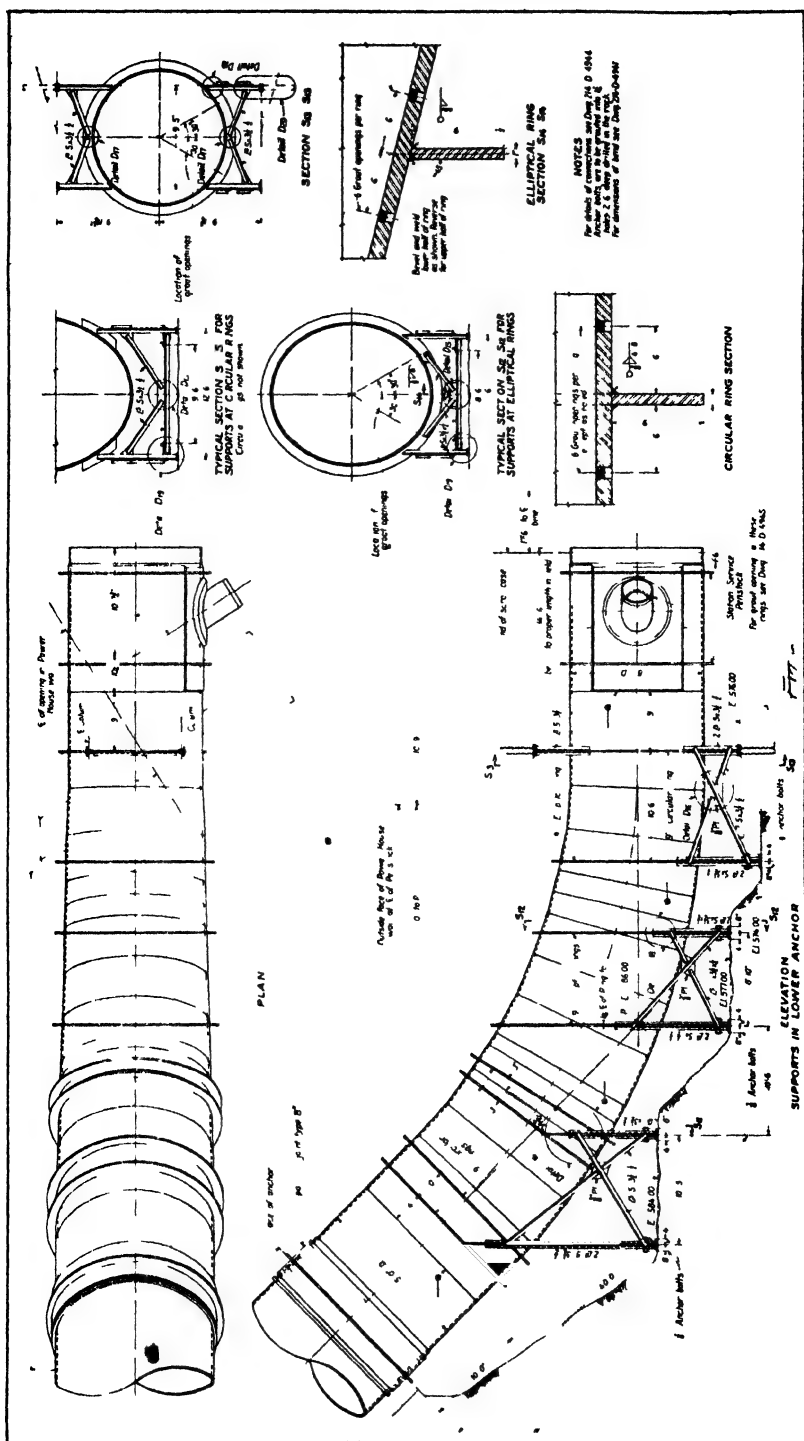



Fig. 6. Supports in lower anchor.

its impact resistance, removing at the same time all residual welding stresses of consequence.

Shop Fabrication—As the penstocks are too large for economical shipment when fully fabricated, the plates are prepared for welding and rolled into half-circles at the Chicago Bridge and Iron Company's plant in Chicago, then shipped to a field fabricating plant erected at Coram, about a mile downstream from the dam. Here the penstocks are fabricated into erection lengths of 20 feet by the Western Pipe and Steel Company, contractor for the fabrication of the penstocks. The field fabricating plant at Coram is equipped with welding, testing, handling and radiographic equipment to complete the fabrication of the penstocks. All butt-welds in the pipe shell are welded on automatic welding machines, depositing the welds in two passes, one on each side of the joint, using a double V-groove in the plates to be joined. For the field-welded joints between shop-sections double V-grooves are used for plates 1½-inches thick or less and double U-grooves for plates over 1½-inches thick. Before any production welding was authorized test plates were prepared of ¾-inch and 2½-inch steel for the qualification of the automatic welding process which the contractor proposed to use. After the adequacy of the welding process was proven by tests made on specimens cut from these plates production welding was authorized. All manual welding operators were qualified by preparing a butt-weld test plate and a fillet-weld break specimen for all-position welding. Control of the welding technique and procedure during production welding is maintained by the preparation of production test plates, by etching specimens, and by stress-relief acceptance tests. Fig. 8 shows a photo-macrograph of a 2½ inch etched weld specimen prepared for that purpose. The macrograph clearly shows the two weld passes and a number of Rockwell "B" hardness readings of the weld and adjoining plate. The hardness values indicate a fairly uniform distribution between a low value of 67.0 in the plate to a high value of 76.3 in the weld (Brinnell 119 to 139.6).

Fig. 9 shows several pipe sections in the course of fabrication in the field fabricating plant and Fig. 10 shows an automatic machine used in welding a circumferential joint, in the Coram fabricating plant. All welds are radiographed with portable X-ray equipment as shown in Fig. 11 and all pipe sections are first stress-relieved in a specially constructed stress-relieving furnace, then hydrostatically tested in the testing machine shown in Fig. 12, before they are ready for installation in the penstock system. Defects disclosed in the welds by the radiographs or in plate and weld metal during the pressure tests are chipped out to sound metal and re-welded. All repaired welds are re-radiographed and the pipe sections re-tested hydrostatically to prove the quality of the repair welds. The bend sections are pressure-tested by welding several bends together with small butt-welds and closing the ends with dished heads. After the tests are completed the sections are separated by flame-cutting without disturbing the original edge preparation for the permanent welds.

Since the penstocks are installed under a separate contract, the specifications required that the erection lengths be made accurately to length and with ends normal to the axis of the pipe within 1/16-inch on the radius to insure a proper fit and alignment in the line when erected. A maximum offset of 1/16-inch was allowed for the inner surfaces between adjoining plate edges at both longitudinal and circumferential joints.

Production tests made of double V-automatic butt-welded joints for a

number of plates varying in thickness from 1⅜-inches to 2⅛-inches showed the following physical properties:

Yield point—all weld metal.................. 39,400 to 49,150 p. s. i.
Ultimate strength—all weld metal.... 61,800 to 68,350 p. s. i.
Elongation in 2-in.—all weld metal......................22.0 to 33.5%
Elongation—free bend specimen...........................33.0 to 50.0%
Appearance—free bend specimen—180 deg. bend, no fracture in welds, only edge tear and plate fracture in two specimens.
Specific gravity of weld metal.................................. 7.81 to 7.87
Nick break—Fine granual texture—no defects.

The following physical properties were found in a number of automatically welded double V-butt-joints for plates from 1¼ inches to 2 inches, after stress-relieving, as determined on stress-relieve acceptance test plates:

	Plate metal	All-weld-metal
Yield point, p.s.i...........	33,330 to 42,660	37,500 to 45,700
Ultimate strength, p.s.i.	54,000 to 63,700	59,500 to 66,070
Elongation in 2-in., %..	30.4 to 43.0	31.0 to 38.2

From the above tests it can be seen that the ductility of the stress-relieved weld metal as revealed by the elongation is only slightly below that of the parent metal and that with modern welding procedures it is possible now to produce welded joints which are about as safe as the plate itself.

Installation—The penstocks are installed by the general contractor of the dam, the Pacific Constructors, Inc. The pipe sections are transported from the field fabricating plant to the dam on a special tractor-drawn trailer. The pipe sections not embedded in the dam are assembled progressively from the anchors and from the ends of the embedded sections, are erected on concrete piers and on temporary supports and placed in accurate position before the joints are welded.

Fig. 13 shows a pipe section being placed in the dam using a cableway supported from the head tower nearby. All girthjoints except the slipjoints at the dam contraction joints are manually welded from both sides of the joint, with weld metal deposited in successive layers and each layer cleaned of all slag and other deposits before the next layer is applied. The projection of the weld reinforcement over the inside surface is limited to ⅛ inch. The specifications require that all welds be peened while hot to relieve stresses and to improve the quality of the welds. The welding in the slipjoints will be performed under proper procedure control and in such a manner as to reduce the residual welding stresses normal to the joint to a minimum, as determined by strain-gauge measurements made at the time of the welding and peening operations. All girthjoints except the slipjoints are radiographed and all defective welds are chipped or ground out to sound metal and the area is re-welded and re-radiographed. All field-welded seams are also to be tested by the magnaflux method of magnetic testing to disclose surface or near-surface cracks in the welds.

Before embedding the upstream sections of the penstocks in concrete the pipe will be securely anchored in place, then thoroughly cleaned on the outside and painted with a cold application coal tar paint to a minimum thickness of $\frac{3}{32}$ inch and the ends of the slipjoints will be wrapped with asbestos sheet packing. Reinforcement steel will be placed around the penstocks and all piezometric and drain connections will be completed before the concrete is poured around the pipe. Internal braces are placed in the pipe during concreting to provent deformations in the shell. The pipe to be supported from the concrete piers and rockers will be adjusted to the

Fig. 7. Expansion joints.

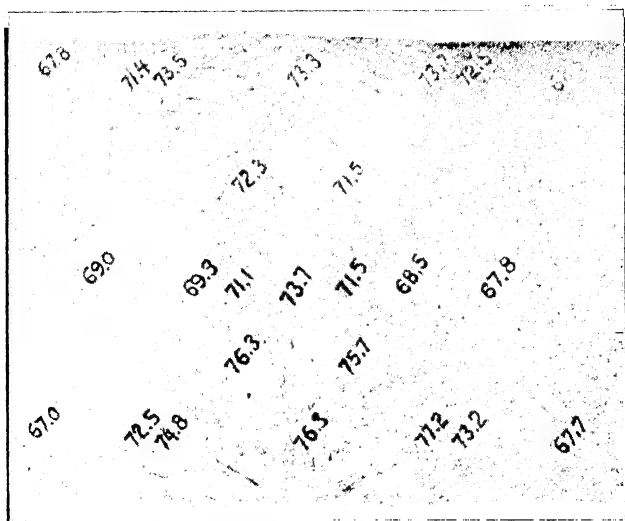



Fig. 8. Hardness readings, Rockwell "B".

proper position for the prevailing temperature by means of a setting chart and the rocker and bearing will be held in position by means of erection plates until the bearing base is grouted to line and grade in the concrete pier and the grout has taken its initial set.

After the erection is completed and before any cleaning and painting is done, each penstock will be subjected to a hydrostatic pressure test of approximately 150 per cent of the pressure for which the penstock is designed. Bulkheads are provided for this test at both ends of the penstocks. After the completion of the pressure test and the repairs necessitated by this test, each penstock will be cleaned by blasting both interior and exposed exterior surfaces and painted with cold application coal tar paint not less than $1/32$-inch and not more than $3/32$-inch thick. Fig. 14 shows the installation work in the dam progressing toward the power house.

All shop and field-fabrication and welding is performed in the presence of government inspectors, who also examine all radiographs for defects and determine areas to be chipped out and to be re-welded, they witness the preparation of the test plates in connection with the qualification and production tests, witness all pressure tests and inspect the completed work to determine whether it meets the requirements of the specifications.

Riveted Design—The use of riveted construction for penstocks of equivalent capacity and for operation under identical heads will necessitate quadruple and quintuple butt-riveted joints with rivets up to $1\frac{3}{4}$ inch diameter to obtain good efficiencies and reasonable shell thicknesses. The longitudinal joints will have inside and outside straps and the circumferential joints will have one double butt-riveted outside strap. The heavy plates involved will make it preferable to drill the rivet holes with all plates assembled to insure a good fit. Rivet holes will be drilled to $1/16$-inch larger than the nominal rivet diameter. The edges of all outside longitudinal butt-straps and of the circumferential butt-straps will be beveled for caulking and the ends of the outside longitudinal butt-straps will be welded to the circumferential butt-straps to eliminate the necessity of scarfing which is not economical for the

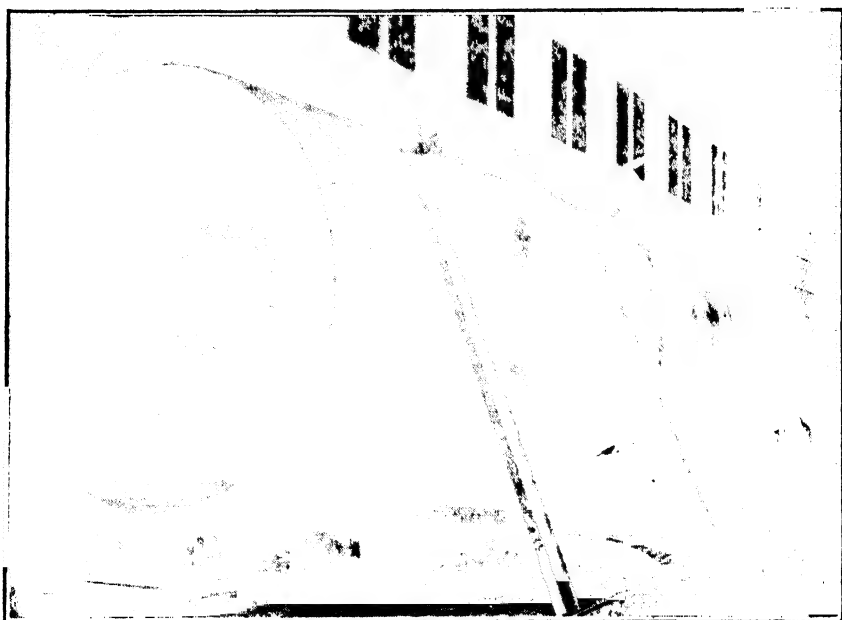



Fig. 9. Pipe sections during fabrication.

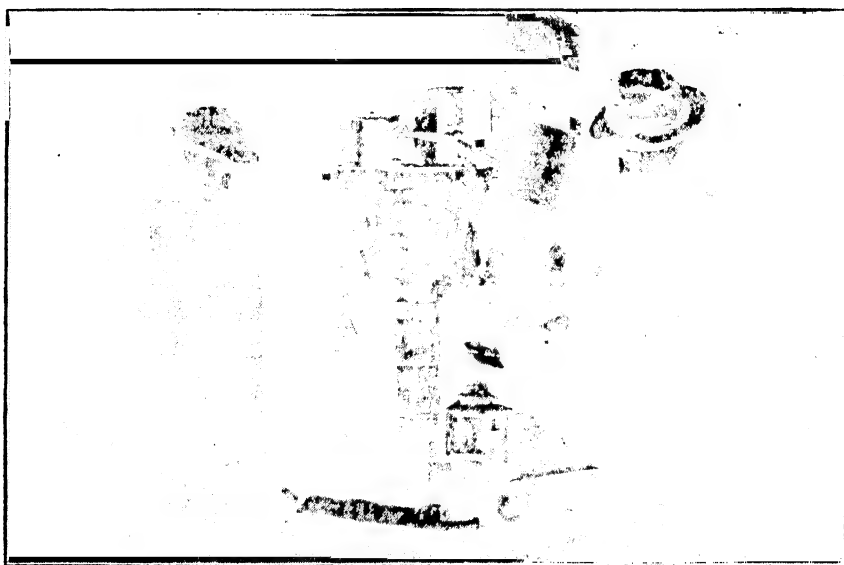



Fig. 10. The welding set-up for circumferential seams.

heavy plates involved. The edges of plates forming longitudinal seams will be planed or machine flame-cut to bring the pipe to exact diameter and to insure joint tightness. The ends of all sections will be trimmed to true lines. No drifting will be permitted for unfair holes. If holes require enlargement to admit the rivets, they will be reamed.

Before riveting all plates must be thoroughly cleaned and freed from rust, scale and burrs and the several plates will be properly aligned and securely held together with erection bolts. Wherever possible, rivets will be driven by pressure tools of sufficient capacity to completely fill the rivet hole and form the head. All rivets shall have full heads concentric with the shank and no re-cupping or caulking of heads will be permitted: All loose, burned or otherwise defective rivets will be cut out and replaced, without injuring the adjacent metal. In order to avoid shrinkage of the rivets on cooling, the riveting pressure shall be maintained on the pressure tool until no part of the head shows red in daylight. All seams must be caulked on the outside in first class boiler work fashion and shall be left uncoated until after all hydrostatic pressure tests are completed. Leaky rivets shall be replaced with new rivets and pipe sections so repaired shall be retested until found watertight under pressures of 150 per cent of the operating pressure.

Hydraulic Considerations—In the construction of penstocks it is important to select a design which will be not only structurally safe but also hydraulically efficient in conserving the available power head. Hydraulic efficiency will also be affected by the condition of the pipe interior. A continuous interior pipe with smooth joints as produced by welding will offer less obstruction to the flow of water and cause less loss in head than a pipe with a rough interior surface as produced by projecting rivetheads and straps in riveted construction. Hence from the standpoint of hydraulics alone the welded pipe will be more advantageous than the riveted pipe and considering equal capacity, the welded pipe need not be as large as the pipe

Fig. 11. X-raying a Joint.

with riveted joints. A hydraulic analysis based on unit No. 3 of the Shasta penstocks will serve to prove this statement.

Diameter of full-welded penstock = 15′–0″
Length of penstock = 865′–6″, (which is the average of the 5 units)
Q = 2800 sec. ft. of flow at rated head.
Max. static head = 479 ft.
Max. water hammer head = 180 ft.
Commercial value of power = 5.68 mills per kw. hr.
Estimated hydraulic energy for sale per year (5 units) = 984,276,000 kw. hr.
Annual value of 1 ft. of head = $14,825 for five units.

Head Losses:

In the straight welded pipe, the head losses, based on Scobey's co-efficient of retardation Ks = .32, will be:

$$H = Ks \frac{V^{1.9}}{D^{1.1}} \times \frac{865.5}{1000} = 2.68 \text{ ft.}$$

Bend losses $C \times \frac{V^2}{2g} = 0.91$ ft. (where C is loss co-efficient based on Thomas' experiments on smooth mitered bends).

The total head loss is 3.59 feet for penstock No. 3. This head loss represents a considerable loss in power revenue. Based on a commercial rate of 5.68 mills per kilowatt hour this head will have a power value of $53,222 per annum for the 5 units. For a riveted pipe of the same diameter the loss in head, based on Scobey's co-efficient of retardation Ks = .52, for plates over ½-inch thick with double butt-strap joints, the loss would be 5.87 feet; evaluated at $87,023 per annum. The capitalized values of these head losses would be $855,000 for the five 15-foot diameter welded penstocks and $1,403,000 for the five 15-foot diameter riveted penstocks (based on interest at 4 per cent, depreciation at 1.78 per cent and operation and maintenance at .42 per cent).

Considering on the other hand, that it were necessary to design riveted penstocks with the same net power capacity as the 15-foot diameter welded penstocks, a diameter must be found which at a flow of 2800 second feet will have an identical head loss. By trial analysis it is found that a 16-foot 9-inch diameter riveted pipe will have a flow and head capacity equal to a 15-foot diameter welded pipe, based on above loss co-efficients in pipe and bends.

Estimated Weight of Welded and Riveted Construction—Considering the larger diameter and the lower joint efficiencies of the riveted pipe (varying from 80 per cent to 93 per cent for the various plate thicknesses as compared to a uniform joint efficiency of 95 per cent for the welded pipe) the shell thickness would be from 16.7 per cent to 33.3 per cent greater than for the 15-foot diameter welded pipe, with an increase in weight of from 49 per cent to 105 per cent. The excess weight of the riveted pipe is partly due to the additional weight of the butt-straps and rivetheads in the joints. The following tabulation based on a detailed analysis of the weight of shell, butt-straps and rivetheads as taken from actual joint designs shows the difference in weight between welded and riveted construction.

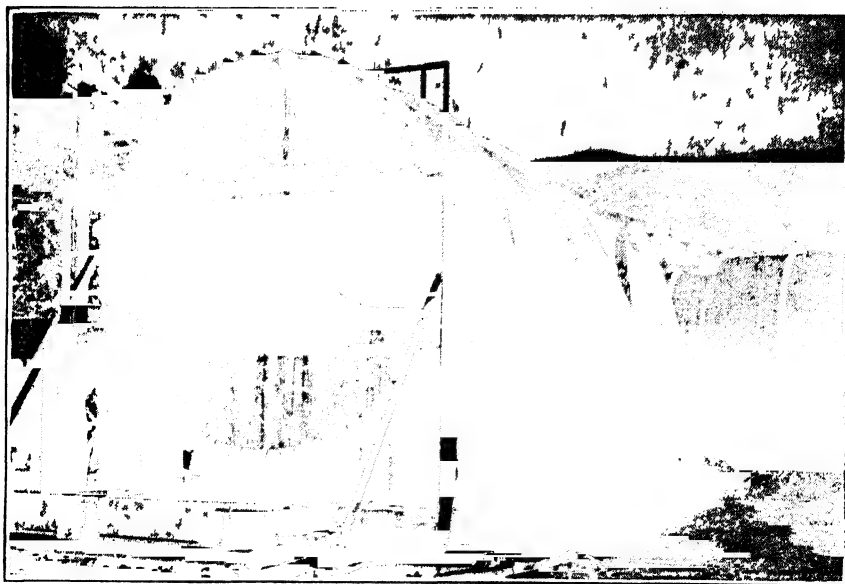



Fig. 12. Hydrostatic test.

15'-0" diam welded pipe — 16'-9" diam riveted pipe

Shell Thickness	Joint Efficiency	Weight of Pipe per Lin Ft	Shell Thickness	Joint Efficiency	Weight of Shell	Weight of Straps and Rivet-heads	Weight of Pipe per Lin Ft
3/4"	95%	1520#	7/8"	89.8%	1978#	447#	2425#
1 1/8"	95%	2285#	1 5/16"	93.0%	2977#	898#	3875#
1 1/2"	95%	3055#	1 3/4"	92.7%	3980#	1460#	5440#
1 7/8"	95%	3820#	2 5/16"	87.0%	5270#	1980#	7250#
2 1/4"	95%	4600#	3"	80.0%	6865#	2595#	9460#

Shells from 7/8-inch to 1 1/4-inches will be quadruple butt-riveted, shells from 1 5/16-inches to 3-inches will be quintuple butt riveted. All weights are based on two longitudinal joints for each pipe and of girthjoints spaced 10 feet apart.

Fig. 15 illustrates graphically the above tabulated differences in plate thickness and weight between welded and riveted pipe.

The above comparison between penstocks applies also to all other water conduits, such as pump discharge lines, where a rough interior such as produced by full-riveted construction would require more powerful pumps to overcome the frictional resistance, or gravity conduits, where only a limited head is available to overcome the friction in the line. The economic trend is the same inasmuch as the smooth interior pipe will carry more water and would be less costly per unit of flow unless the riveted pipe could be fabricated at a considerably lower cost than the welded pipe. In the following cost analysis it will be shown that this is not the case.

Estimated Costs—The cost of the welded pipe consists of the cost of the steel, layout work, plate preparation, rolling, welding, weld examination, stress-relieving, pressure testing and installation. The cost of the riveted pipe consists of the cost of the steel, layout work, plate preparation, rolling,

drilling, riveting, caulking and sealwelding, pressure testing and installation. The cost of the latter items varies with the size of the rivets for each plate thickness. The unit costs of these variable items were computed for each plate thickness and a weighted average price per pound was taken to represent all plate thicknesses. A waste of 1½ per cent was allowed for the cutting and preparation of the plates received from the mill.

Cost of five 15-ft. diam. welded penstocks (from contractor's bid)

Item	Quantity	Unit Cost	Item Cost
120" wide steel plates	14,880,000#	.0235	$349,680
Shop fabrication and testing	14,660,000#	.095	1,392,700
Transportation—prefabricated plates	14,660 000#	.0117	171,522
Radiographic examination—shopjoints	25,000 lin. ft.	$1.25	31,250
Stress-relieving	14,660,000#	.005	73,300
Hauling of pipe sections	14,660,000#	.002	29,320
Installation and testing	14,660,000#	.016	234,560
Radiographic examination—fieldjoints	9,000 lin. ft.	$1.75	15,750
Sand blasting and painting	355,000 sq. ft.	.075	26,625
Total cost of construction			$2,324,707

Cost of five 16'-9" diam. riveted penstocks

Item	Quantity	Unit Cost	Item Cost
120" wide steel plates	26,100,000#	.0235	$613,350
Shop fabrication and testing	25,830,000#	.100	2,583,000
Transportation—prefabricated plates	do	.0117	302,211
Hauling of pipe sections	do	.002	51,660
Installation and testing	do	.015	387,450
Sand blasting and painting	400,000 sq. ft.	.075	30,000
Total cost of construction			$3,967.671

Proportionate Savings Due to Welding—The above estimates show a total construction cost $2,324,707 for the welded penstocks and $3,967,671 for the riveted penstocks, both of equal flow capacity and net power head. The saving in weight for the welded construction is 11,170,000 pounds or 43.2 per cent, and the unit cost of the welded pipe is $0.158 per pound and of the riveted pipe $0.153 per pound. These costs are only for the steel pipe and do not include the cost of excavation, concrete piers and anchors which in this case comprise about 13 per cent of the cost of the steel pipe, increasing thus the entire installation to approximately $2,627,000 when welded and to approximately $4,483,000 when riveted. The total possible saving in cost by using a welded construction will be about $1,856,000 or 41.4 per cent of the cost of the riveted construction.

Estimated Annual Gross Saving Due to Arc Welding—(a), The Bureau of Reclamation constructed, during the past five years, an average of about $1,100,000 worth of steel penstocks and $200,000 worth of other steel water conduits annually, all of arc welded construction. If these pipe lines would have been of riveted construction, the cost would have reached about $2,220,000 per year, when based on above analysis. An annual saving of about $920,000 was thus possible by modern welded design and construction.

(b), By industry in general the annual gross savings due to arc welded penstocks alone may be estimated from the annual increase in installed capacity of hydroelectric energy in the United States. This increase varied from year to year and was estimated at 480,000 kilowatts for 1941 and at 1,020,000 kilowatts for 1942, which may have been considerably increased

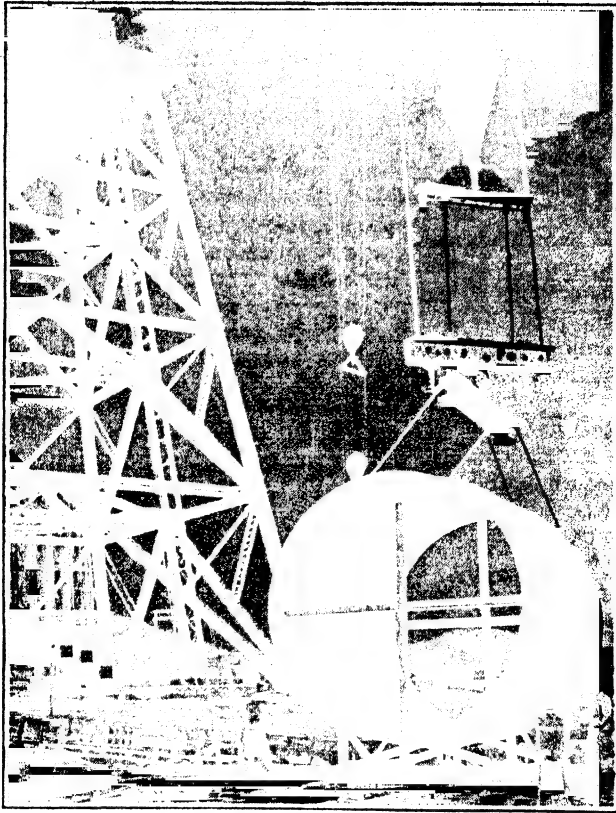



Fig. 13. A fabricated section.

because of the increased power requirements of our war industries during these years. Using the construction cost of riveted penstocks estimated for Shasta Dam, the unit installation cost would be $\frac{4,483,000}{375,000} = \$11.95$ per kilowatt of installation, for an installed capacity of 375,000 kilowatts. With an estimated saving of 41.4 per cent, the annual saving possible with arc welded penstocks may be computed at $11.95 \times .414 = \$4.95$ per kilowatt installed. Accordingly, the annual saving in installation cost may be estimated as follows:

For 1941 the saving would be........................ $480,000 \times 4.95 = \$2,376,000$
For 1942 the saving would be........................ $1,020,000 \times 4.95 = \$5,049,000$

The entire installed hydroelectric capacity of the United States on January 1, 1941, was 11,675,300 kilowatts. Adding the scheduled increase since then, the generating capacity on June 1, 1942, presumably was 12,700,000 kilowatts. There are no figures available but it may be assumed that at least 75 per cent of the penstocks serving the plants which make up this total are of riveted steel construction, the other 25 per cent being divided between woodstave, concrete and welded steel construction. Using the above estimated unit saving of $4.95 per kilowatt of installed capacity, a total saving in construction cost of $47,148,750 could have been effected, if it would

have been possible to use arc welded design and construction at the time when the plants were built This saving would be proportionally larger if applied to all other water conduits such as pump lines, siphons, water supply lines, aqueducts, etc, of which there is no complete record available

Increased Service Efficiency—In riveted pipe the heavy butt-straps and rivetheads projecting into the interior of the pipe interrupt the smooth flow of water, producing a disturbance and setting up eddy currents at each projection Each rivethead will be subjected to some cavitation at its down-stream side, which eventually will remove the paint and attack the metal underneath, requiring more frequent cleaning and painting In pipe lines carrying water with a high silt and sand content, the rivetheads near the invert of the pipe are often worn off by the continuous abrasive action of these suspended solids This not only removes the paint from the rivetheads but in time may weaken the rivetheads sufficiently that replacements are necessary

From the standpoint of stress on the other hand, a riveted joint is not capable of transmitting the hoop tension between adjoining plates of the shell as uniformly and efficiently as in a butt welded joint The reason for this lies in the fact that many of the rivets in a joint because of their location with respect to the point of stress in the shell or due to the restraining action on the heavy butt straps and a poor alignment in the rivet holes, may not carry their proportionate share of the load, which often results in the over-stressing of other rivets closer to the point of stress in the shell This condition becomes more pronounced with increasing shell thickness and correspondingly heavier butt-straps The latter having also the effect of reducing the net cross sectional area of the pipe increasing thereby the velocity and head loss In a 16 foot 9 inch diameter riveted pipe with two longitudinal joints as considered above the inside straps for the 3 inch shell

Fig. 14. Installation work near power house.

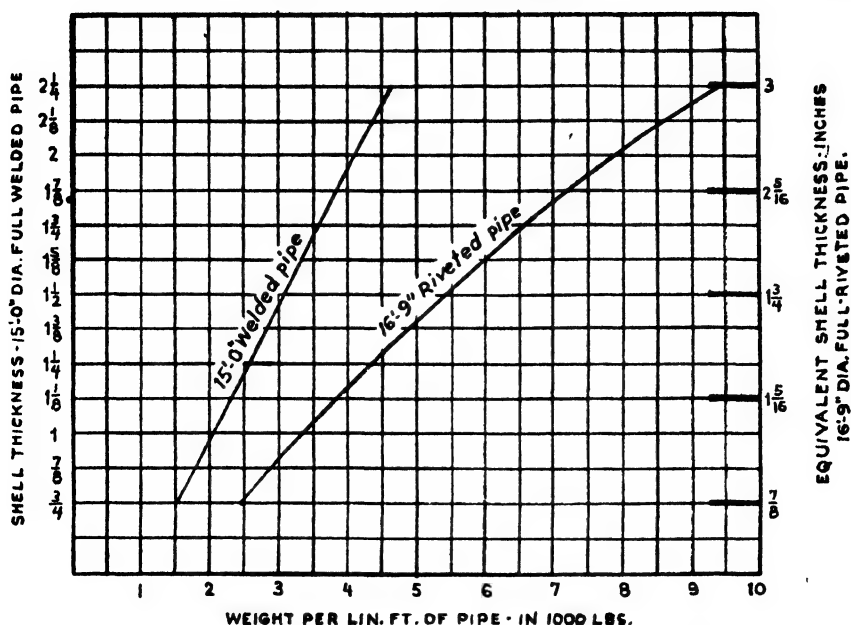



Fig. 15. Comparative weights of welded and riveted steel pipe of equal flow and friction head.

would decrease the net area by two square feet approximating nearly one per cent of the total and increasing the velocity and friction head proportionally. In comparison a double butt-riveted pipe will have a uniform and concentric stress-transmission in the shell, a smooth interior without interruptions in the surface or changes in cross-sectional area. This will produce a smooth, even flow, free from eddy currents and cavitational disturbances. The result will be a reduction in vibration and in cavitation with its destructive effect on paint and metal, all contributing to a longer useful service of the pipe line and to reduced shutdowns for maintenance. The increased flow efficiency made possible with welded pipe has been proven in the hydraulic analysis above.

Social Advantages—The adoption of welded construction will not only produce absolutely watertight conduits but will, on the other hand, yield considerable social advantages. As shown above, the penstocks analyzed will result in a considerable saving in steel plate amounting to about 43 per cent. This large saving in a vital natural resource is of great importance at any time, but can be more fully appreciated during the present emergency, when it is of prime importance to divert all available strategic materials, of which metals are the most crucial, to defense purposes to protect our way of life. By the use of the hydraulically more efficient welded steel penstocks or pumping lines, our water power resources will be utilized more efficiently and society in general will benefit from this better utilization and reduced construction cost by enjoying the lower power rates resulting from it. Life and property will be more fully protected by the safe construction made possible in using ductile steels properly welded and tested, assuring thus a welded job capable of safely withstanding shocks and impact loads due to water hammer and seismic disturbances.

Chapter V—Welded Water Wheel Center Casing

By W. W. Armour

Vice-President, Armour's Pattern Shop Co., Welding Engineers, Worcester, Massachusetts

'W. W. Armour

Subject Matter: A welded water wheel center casing for 40-inch runners. The casing consisted of two parts with bolting flanges along the center line of intake opening. Designed so that various sections could be cut from a flat plate and rolled to the desired curvatures. The casing was constructed with two 41½-inch diameter intakes and a 66 inch diameter outlet. The shell thickness was ⅜-inch. A wooden form of inside dimensions of the shell was made. Paper templates of each segment of shell was made and the plate was cut to size and segments were welded together. The weight of the shell was one-half of what a cast iron shell would be. The advantages are less cost for metal and no pattern required.

In presenting this paper under the above subject, it is recognized that the construction of water wheel casings or turbine shells by welding is not a new idea, but it is believed that this paper introduces a new method of procedure.

Design—The casing, (See Fig. 1), was designed to consist of two parts: the upper half and the lower half, with bolting flanges along the center line of the intake openings. The design was also carried out with the intention of reducing, as much as possible, the amount of warped surfaces on the shell, so that the various sections of the shell could be cut from flat plate and rolled to the desired curvatures. It was also designed symmetrically about the vertical axis so that the various segments of the shell were duplicated. This idea may be readily understood by referring to photographs.

A water wheel casing of this design was constructed with two 41½-inch diameter intakes and a 66-inch outlet. The overall length of the shell at the intakes was 9 feet 3½-inches. The distance from the center of the intakes to the outlet flange was 3 feet 5¼-inches. The thickness of the shell was ⅜-inch.

An allowance of ¼-inch for machining was provided on the faces of the bolting flanges.

Procedure—First, a wooden form of the inside dimensions of the shell was made. This form was made of built-up oval shaped sections at each joint or weld. The amount of oval corresponds to the allowance provided for machining on the bolting joint flanges. These wood sections were strongly braced to each other so that the form would support the weight of the shell plates and also permit the use of clamps to hold the plates in place.

Paper templates were then made of each segment of the shell, transferred to a steel plate and flame cut to size.

These various segments were then rolled to fit templates corresponding to the oval sections of the form, and where the segment did not exactly lie

to the form, it was pulled down by clamps. The segments fitting at the intake openings were put on the form first. Then segments fitting next to them were placed on the form and tack-welded to the first segments. This procedure was carried out until the shell was completed and tack-welded.

The intake and outlet flanges were then set in place and tack-welded. Clip plates were welded across the joints of the intake flanges to keep them in proper alignment during welding.

The longitudinal ribs and bearing box on the upper half of the shell were fitted into place and tack-welded.

The wooden form or skeleton was knocked out and the segment joints were welded inside and out The shell was put in position so that most of the welding was accomplished down-hand

After the seams of the shell were completely welded, the center line of the joint was scribed on the shell Lines ¾-inch on each side of the center line were also scribed on the shell The section between the two lines on each side of the center lines was cut away with a cutting blow-pipe. The bolting flanges were then fitted to the shell on each side of the center line and welded in place as shown on the photographs The hand-holes and small ribbing were then completed

The tack-welds of the intake flanges were then broken where necessary and the flanges were squared and aligned parallel, tack-welded in place and welded complete

Observations—The wood form enabled us to assemble the segments of the shell, and served as a jig to keep the correct dimensions of the shell throughout

When the shell was cut away for the joint bolting flanges, there was

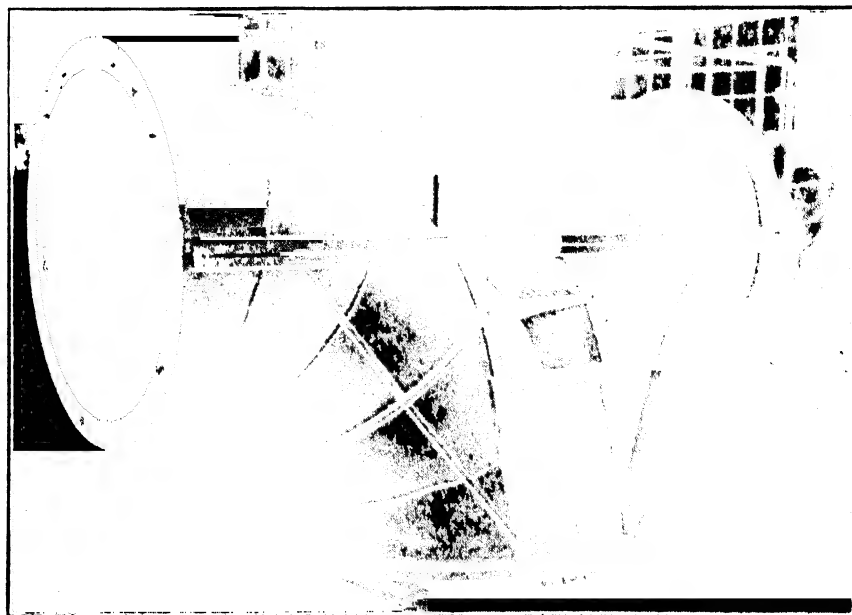



Fig. 1. Welded water wheel center casing.

only a $\frac{1}{8}$-inch bow of the top half of the shell. No effort was made to correct it, because it was believed that when the joint flanges were welded, some of this bow would be removed. This proved to be the case, as only a $\frac{1}{16}$-inch bow remained at the joints of the intake flanges.

Welded Construction Compared with Iron Casting—Water wheel casings of the approximate size as the one described, have been made of cast iron. Good foundry practice would dictate that the thickness of the shell would have to be at least $\frac{3}{4}$-inch thick so that the iron could fill the mould rapidly without chilling too much.

Therefore, at the outset, the welded construction method affords approximately a 50 per cent saving in weight over the casting method.

The usual method of making a cast iron shell is to provide patterns or a skeleton from which the mould can be made, and also core boxes or skeleton arbors for making the cores of the shell.

Complete patterns and core boxes would constitute an expensive item of the cost of the shell; whereas, a skeleton pattern and skeleton core arbors, although costing about the same as the wood form used in the welded construction method, would add materially to the moulding costs. Shell castings, made by using skeleton patterns by sweeping up the moulds and cores, sometimes vary in thickness as much as $\frac{3}{4}$-inches. Therefore, welded construction for water wheel casings has the advantage of uniform thickness of material.

Another advantage which the welded water wheel casing possessed over the cast shell was a 15 per cent saving in cost.

Conclusion—Welded construction for a water wheel casing such as described in this paper proved to be a more advantageous method of production than if it had been made of cast iron.

Chapter VI—All Arc Welded Steam Line

By William A. McGee

Mechanical Engineer, The New York Central Railroad Co., Cleveland, O.

William A. McGee

Subject Matter: Steam line designed to carry 34,000 pounds of steam per hour located in a plant which has a locomotive repair shop and a round house. The pipe is 2,000 feet long and traverses 700 feet of tunnel, 360 feet in underground conduit and the balance in risers and overhead line. The line is 8-inch lap welded steel pipe in 20 and 40 foot lengths and with ends beveled for welding. The estimated savings by welding is $2,486; this also includes labor time which would have been needed to protect flanges. The estimated savings in the railroad industry is $350,000 for like work per year.

The 8-inch steam line is designed to carry 34,000 pounds of steam per hour at 145 pounds initial gauge pressure and 75 degrees F. superheat.

The plant contains a 36-pit locomotive repair shop and a 49-stall engine terminal round house.

Approximately one heavy repair (Class 2-3) locomotive and one-half light repair locomotive are turned out each day at the locomotive repair shop and from 140 to 150 locomotives are handled at the round house each 24 hours.

Formerly, two separate power plants served these shops, one located at the locomotive shop and the other at the round house.

With the construction of the line in question, the power plant located at the round house was shut down; one 500 horsepower boiler in this plant was retained for use in emergencies and during extremely cold days in winter.

A net annual saving in operation of approximately $10,000 is made by this arrangement.

Some of the details of the line are shown in Fig. 1.

The peak requirements at the round house amount to approximately 34,000 pounds of steam per hour.

Problems incidental to construction of the 2,000-foot pipe line required careful planning, as it traverses through approximately the following: 700 feet of tunnel, 360 feet in underground conduit, and the balance in vertical risers and overhead in buildings; a portion of the underground line in conduit crosses under two railroad tracks and one trucking road.

The line is constructed of 8-inch lap welded steel pipe, 28 pounds per foot, 0.322-inch wall thickness, and was supplied in 20-foot and 40-foot lengths, with plain ends beveled 37½ degrees for welding.

All elbows are of seamless steel "tube-turns" and lateral outlets are "Weldolets"; there are no threaded flanges or fittings in the line; gate valves are 250 pound pressure ferro-steel and flanges are 300 pound pressure forged

Fig. 1. 8-inch pressure steam line.

steel slip-on type; special ⅞-inch steel studs were used in all flanged connections and flanged fittings.

Great care was exercised in determining the number, kind and location of expansion joints. At all locations, except in the tunnel, long radius expansion loops and "U" bends were used; a 300-pound working pressure, cast steel, double, internal-external guided type expansion joint was used in tunnel.

The line is insulated with sectional covering, 2-inches thick; the portion underground is encased in spirally corrugated iron conduit, the outside of which was treated with asphalt and felt-wrapped.

Attention is called to the unique method of supporting the line which spans the distance of 38-feet 6-inches between stationery storehouse annex and electrical building. This method of welded support eliminated the use of a column support, which would have obstructed a trucking driveway at this location.

Regarding the saving:

Our largest saving is from the increased life of arc welded over the conventional method of pipe with screwed-on flanges or couplings. Pipe, to a large extent, fails at the threads and not in the body or thicker part of the pipe. The threading of standard pipe reduces its thickness about one-third, while welding has a tendency to slightly increase the pipe thickness at location of weld. On this premise, the arc welded pipe should endure approximately 33 per cent longer than the threaded pipe; however, the writer has installed a number of welded lines, sizes two to six inches, in various locomotive round houses, and has found that these welded lines have given more than double the life of threaded pipe lines of similar sizes.

The cost of installation also is in favor of the arc welded over that of the threaded line.

The 8-inch line described above cost approximately $14,000 for complete installation.

The saving of welded compared with threaded and flanged joints in this line was as follows:

Threaded Flanges

Item	Cost
2—8″ Ex. Heavy Screwed Flanges	$11.10
1—8″ Gasket	.40
1—Set of Bolts	1.20
Cost of Threading Pipe	2.00
Freight Charges and Handling	.40
Labor attaching flanges to pipe and refacing same	3.50
	$18.60

Arc Welded Joint

Item	Cost
Power	$ .25
Welding Rod	.21
Beveling Pipe	.00
Labor	1.04
	$ 1.50
Difference in cost	$17.10

Line contained approximately 110 joints.

Saving (110 × $17.10) = $1,881—which equals about 13.43 per cent saving over screwed flanges.

Another sizeable saving is that of insulation or pipe covering.

Application of insulation on the welded steam line, due to absence of flanges, saved some labor time over that formerly required for this work, also considerable saving is made in cost of material due to elimination of covering of flanges, as follows:

Cost of covering material and labor applying same:

For set of 8″ flanges	$6.50
For welded joint	1.00
Difference	$5.50

Saving in covering of 110 joints on line in question (110 × $5.50) is $605, or about 4.3 per cent.

From the above it appears that a saving of $2,486 ($1,881 plus $605) or 17.75 per cent was made by application of arc welded joints.

This pipe line has been in service since the fall of 1941 and has given no trouble whatever from any of the welded joints.

The job has proved so successful that we contemplate welding all major steam line work in the future.

We probably spend from $75,000 to $100,000 per year on an average for this class of pipe work.

There are, in round numbers, about 1,000 railroads in the United States; therefore, if we assume that on an average each will spend only $2,000 per year on pipe work of this nature, a saving of over $350,000 per year could be effected by arc welding.

SECTION IX

Machinery

Chapter I—Fabricated Rolled Steel Machinery

BY JOHN O. OGDEN AND E. J. ELDRIDGE

General Manager and Director, and Draftsman, respectively, Welded Products, Pty. Ltd., Sydney, Australia

John O. Ogden

Subject Matter: A number of heavy-duty metal working machines built in Australia, such as forging presses of crankless type (capacity 300-tons); guillotine shears (capacity 10-feet by 1-inch); plate edge planing machine (capacity 20-feet by 1½-inches); punching machine (capacity 2-inches through 2-inches of mild steel); shearing machine (capacity 1¾-inch mild steel plate, 42-inch gap). Paper discusses steps necessary to evolve a satisfactory design of the frames. Calculations for all welds are given. Cost analyses indicate savings ranging from 32 per cent to 45 per cent. Advantages listed by authors include: greater reliability and flexibility of design, faster production, better appearance, increased efficiency.

E. J. Eldridge

In all the amazing developments of the welding science, there are few to equal the developments in the metal working machine tool manufacturing industry. This is particularly the case in Australia, where an exceptionally wide variety of machinery has to be produced to meet the demands of a comparatively small market. It is not possible in Australia, except in a few instances, to produce machinery on anything like a mass production basis, one or two of a particular machine being the rule rather than the exception. This small market coupled with the wide variety of machinery required rendered it imperative to develop some means whereby these difficulties could be overcome. This obviously was not possible if it were necessary to utilize cast iron or cast steel machine frames, as the pattern cost would be prohibitive. Importation also presented many difficulties, in that often the machinery available on the overseas market was not quite suitable for the particular purpose in view, this necessitating makeshift arrangements.

It was to overcome these difficulties that the firm with which the writers are associated commenced operations some seven years ago. The basic idea behind the foundation of the company was to produce machinery at a competitive price which would exactly meet the requirements of the pur-
working machinery.

The wide experience of the founders of the company indicated that chaser, this service at the same time covering a very wide variety of metal

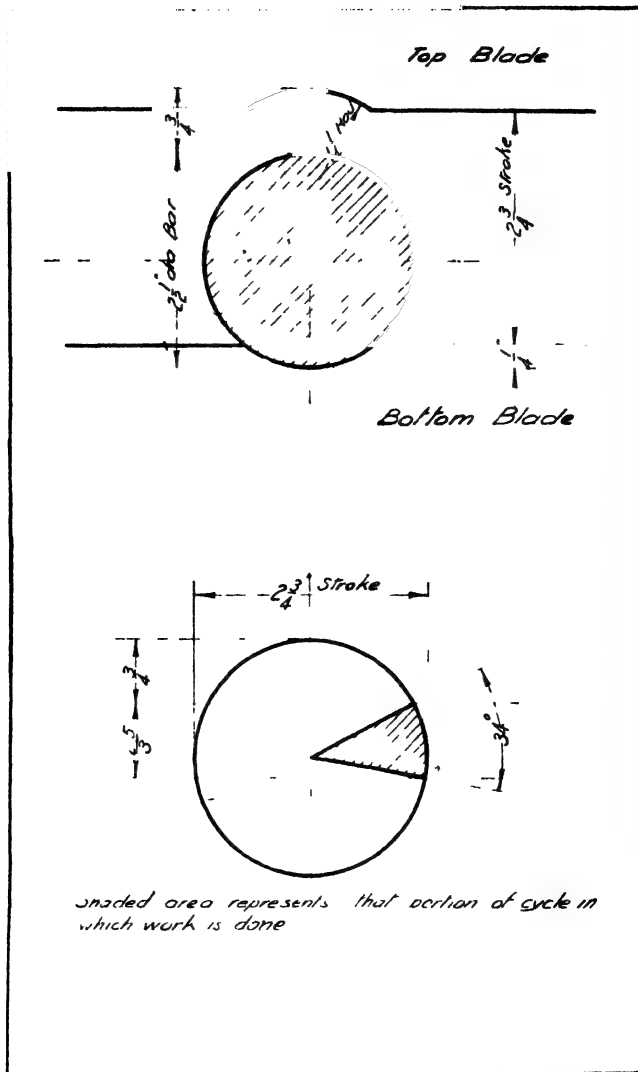



Fig. 1. (above). Preliminary blade lay-out. Fig. 2. (below.) Cycle of operation.

there was a big potential demand for heavy duty machinery, equipped with unbreakable frames, as in practically every large industrial undertaking examples of broken and welded-up machine frames of cast construction could be seen. Further, a survey of the products of Australian manufacture and of the importation data showed that there was no local supplier of really heavy duty metal working machinery, such as presses, guillotine shears, punches, croppers, bending rolls and similar equipment, and it was in this particular line of manufacture that the company decided to specialize though a large variety of other work has also been handled since the inception of the company. In fact, as an indication of the variety of machinery produced, it may be said that over six hundred different designs of machines

have been turned out in the past seven years, and in all these hundreds of designs not one cast steel or cast iron frame has been utilized, the whole of the output being equipped with fabricated rolled steel machine frames.

It will be appreciated that seven years ago there was not the generally favorable acceptance of welding among the engineering fraternity of Australia, as is the case today, and a great deal of pioneering work was necessary to overcome the somewhat natural prejudices which then existed. In fact, it may safely be said that the fabricated machine frame forced itself into favor by the excellence of its performance, and in spite of the volume of uninformed criticism which existed against it.

The acceptance of the welded machine frame was probably brought about by three factors (1) the excellence of the project, (2) the pleasing modern appearance of the resultant machinery, and (3) the possibility of cost savings by the adoption of this method. The latter factor is placed last on the list, as it has always been the contention of the writers' company that the prime cost of necessary equipment was the least important, as superior performance would rapidly prove that the possible higher outlay was a good and profitable investment.

Accordingly, therefore, it has never been the policy of the company to produce machinery on a price basis, the only standard worked under being the proved excellence of the design, the cost being regarded as a secondary consideration. The soundness of this policy is amply borne out by the repeated orders for identical machinery from the big industrial undertakings of Australia.

The foundation of the company was very materially assisted by the relatively low cost of the equipment necessary to produce fabrications as compared with the cost of equipping a foundry capable of handling similar sized units. In the establishment of such an enterprise the essential equipment consists of an oxy-acetylene or oxy-coal-gas cutting machine and a welding set of sufficient capacity to handle large size electrodes, together with sundry auxiliary equipment, such as grinders, handling equipment, etc. To these bare essentials of equipment there must of course be added a designer of wide imagination, capable of divorcing his mind from conventional ideas of machine design, and this man is the real heart of fabricated machine tool construction. The equipment mentioned is the nucleus of the fabricating shop and calls for but a small capital outlay. This equipment can be elaborated upon and added to indefinitely, but with this equipment a surprisingly wide range of fabricated work can be undertaken and all subsequent elaborations branch out from these few machines. Thus it will be seen that it was possible to establish a flourishing concern with a very small capital outlay and to develop the Plant and equipment in a parallel manner to the development of the market for the project.

In considering the development of the fabricated rolled steel machine frame, it must always be stressed that the advantages of this type of construction are many and varied, and while the reduction of cost is important, there are other factors which are even more important from the user's point of view. These may be summarized as greater reliability, a vastly greater factor against possible damage through accident, greater rigidity, greater lightness and finally the flexibility of design possible through the use of this medium.

Thus, it is possible to design, say a guillotine shears, capable of shearing 1-inch mild steel plate 10-feet wide with a net weight of only 65,000-pounds, and yet produce a machine which is rigid, and the frame of which our

company is prepared to guarantee unbreakable without reserve. An illustration of this machine is given herewith as Fig. 10.

A somewhat similar example of strength with lightness is in the case of the 300-ton capacity crankless type forging press, (See Fig. 11). The main units in the design of this machine frame are 4⅝-inch mild steel plates 16-feet long and 5-feet wide, which are built into a series of box sections by means of side plates and cross members, the whole resulting in an exceptionally rigid unit, which is free from harmful deflection, thus resulting in increased die life, this frame also being guaranteed unbreakable without reserve.

A further example of rolled steel fabrication is shown in the all steel plate edge planing machine, (See Fig. 12). In this case the entire machine is of fabricated construction. The front table and slide ways for the carriage are of steel, as also is the carriage, bronze slippers being introduced between the two steel faces to ensure correct anti-frictional qualities. This machine, which is of all electric control, is of most pleasing appearance and very clearly illustrates the contention that the modern lines of a fabricated machine are just as attractive, if not more so, than the older style of cast construction. This machine could definitely not have been built in Australia without the use of welding.

As a final example before dealing in detail with the manufacture of a fabricated machine, we would illustrate a large punch and shearing machine, (See Fig. 13) which has a somewhat interesting history. The machine was required for a new shipyard which was being established, the delivery being of the utmost urgency. Our company was first called in in January 1940, the order was placed with us in February, and 16 weeks later the machine was shipped ready for use, in which time it had been designed and built from scratch with no preliminary design data. The main problem in the construction of this machine lay in obtaining sufficiently large steel plates for the side frames. The plates required were 20-feet long by 7-feet 6-inches wide by 3-inches thick, this size being beyond the capacity of the local mills, while the importation of the plates was too indefinite to consider. The problem was overcome by laminating three 1-inch plates of the required size into one 3-inch plate, the plates being welded all around the edges and further welded together round all the apertures, while a certain amount of plug welding was resorted to in addition. The method of carying out this lamination is illustrated in the attached photograph, Fig. 14. It will be noted that the center plate is set in about ¾-inch between the two outside plates, thus enabling fillet welding without the necessity of preparing the fillet joint beforehand. Further, the center plate is set up about ¾-inch higher at the top than the two outside plates, which of course leaves a recess of about ¾-inch at the bottom. Thus, once again fillet welds are possible without preparation. In fact, the only necessity for preparation was around the various apertures, subject to subsequent machining operations. It may therefore truthfully be said that without the use of welding this machine could not have been built in Australia, and keels could not have been laid to schedule six months after the commencement of the construction of the shipyard.

The foregoing instances illustrate very clearly the value of the fabricating process in the manufacture of heavy duty metal working machines, and we now propose to detail the steps necessary to evolve a satisfactory design of machine frame.

The machine selected for analysis is an open fronted bar shear capable

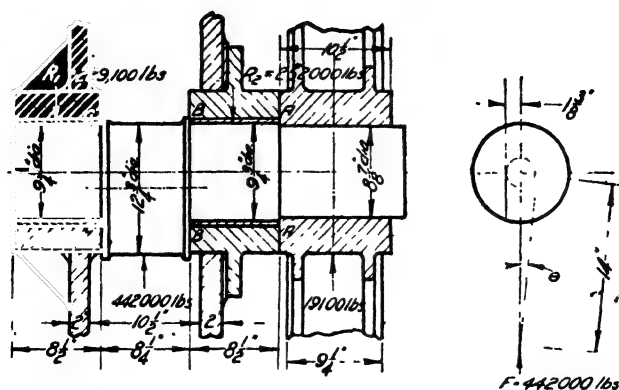



Fig. 3. Preliminary lay-out of main shaft.

of cropping $2\frac{1}{2}$-inch diameter rounds in 65-ton tensile steel with an operating speed of 15 strokes per minute rated for continuous cropping. This is exceptionally heavy duty work for an open ended shear, as the maximum load is taken when the stroke has only travelled 10 per cent or 15 per cent of its full one-half cycle. Further, it is essential to prevent any springing in the cutting blades, as spring or deflection would be fatal to the life of the cutting edges in work of this kind.

In machines of this type the forces acting on the frame and the corresponding stresses induced are so complicated that mathematical analysis is impossible to any degree of accuracy.

In these machines where accurate alignment is required, rigidity is more important than actual strength. Since it is possible to compute the stresses and strains only in the simplest of machine frames, the judgment and experience of the designer must govern to a great extent the design of the frame.

The steel selected as being the maximum capacity of the machine is a high carbon steel 1.00 to 1.15 per cent carbon with an ultimate tensile strength of 150,000-pounds per square inch and an ultimate shear strength of fs = 90,000-pounds per square inch.

Area of section to be sheared: $A = \dfrac{\pi \times 2.5^2}{4} = 4.908$ sq. ins.

Force required for shearing: $F = A \times fs$ . . . . (1)

$= 4.908 \times 90{,}000$

$= 442{,}000$ lbs.

[b] It has been established by experiments that a bar is completely sheared before the blade has passed one-third of the distance through the material. Therefore, the work done by the shear is done during this period.

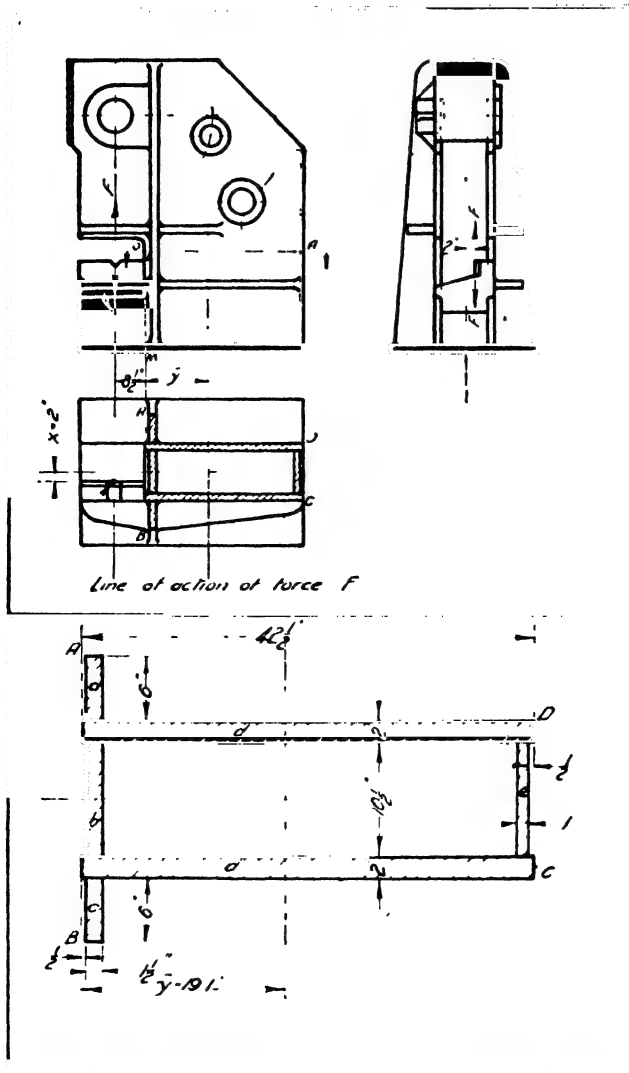



Fig. 4, (top). Diagrammatic sketch of frame. Fig. 5, (bottom). Section 0A.

Stroke of Ram = 2¾ (determined by preliminary layout of blades), (See Fig. 1).

By drawing a circle representing the stroke of the ram, (See Fig. 2), we can now determine the time in which the work is done and also the work done.

Work Done:

$$E = FS \quad \text{. . . . .} \quad (2)$$

where S is the distance through which the Force F acts in feet.

$$E = \frac{442{,}000 \times 2.5}{12 \times 3} = 30{,}720 \text{ ft.-lbs.}$$

Period in which work is done:

$$\text{Time of complete stroke} = \frac{60}{15} = 4 \text{ seconds}$$

$$\text{Time in which work is done} = \frac{4 \times 34}{360} = .378 \text{ sec.}$$

Since we now know the work done and the period during which it is done, we can find the power required to be transmitted through the gearing from the flywheel to the ram and also the power of the motor required to bring the flywheel back to full speed before the next power stroke.

Horsepower transmitted by gears:

$$\text{H.P.} = \frac{\text{Work Done (ft.-lbs. per minute)}}{33{,}000} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$= \frac{30{,}720 \times 60}{.378 \times 33{,}000} = 148 \text{ H.P.}$$

Since 30,720 ft.-lbs. are transmitted in .378 sec.

$\frac{30{,}720}{.378}$ ft.-lbs. are transmitted in 1 sec.

$\frac{30{,}720 \times 60}{.378}$ ft.-lbs. are transmitted in 1 min.

Motor Horsepower:

Time in which work is done by motor

$$= \frac{4 \times (360 - 34)}{360} = \frac{4 \times 326}{360} = 3.62 \text{ sec.}$$

$$\text{H.P.} = \frac{30{,}720 \times 60}{3.62 \times 33{,}000} = 15.4 \text{ H.P.}$$

Gearing:—The next step is to determine the ratio of gearing assuming a flywheel speed of from 400 to 500 revolutions per minute, which is our usual practice, and also to determine the size and other data of the gears required.

Thus, if we assume a flywheel speed of 450 revolutions per minute the total

$$\text{reduction of gearing} = \frac{450}{15} = 30 \text{ to } 1.$$

We now select a double train based on experience and decide on a ratio of 6 to 1 for the main gears and 5 to 1 for the first motion gears.

The gears of a heavy-duty bar shear are naturally subjected to an overload every revolution and therefore should be made sufficiently large to withstand this overload continuously. This is the case in the main gears.

The horsepower formulæ now used are based on the British standard specification for machine cut spur wheels. Two formulæ are given (1) deals with tooth strength in relation to horsepower and (2) deals with tooth wear in relation to horsepower. Each gear should be calculated for strength and wear giving four power ratings for each pair of gears and the smallest of these is the allowable horsepower for that pair of gears.

The British Standard Specification Formula:

$$\text{H.P. for Wear} = \frac{\text{Sc} \times \text{X} \times \text{Z} \times \text{F} \times \text{R} \times \text{N}}{\text{K} \times \text{P} \times 126{,}000} \quad \ldots\ldots\ldots\ldots (4)$$

$$\text{H.P. for Strength} = \frac{\text{Sb} \times \text{X} \times \text{Y} \times \text{F} \times \text{R} \times \text{N}}{\text{P}^2 \times 126{,}000} \quad \ldots\ldots\ldots\ldots (5)$$

Sc Basic surface stress factor (depending on material)
Sb Basic bending stress factor (depending on material)
X Speed Factor (Tables) 15 R.P.M. X = .540
90 R.P.M. X = .425
450 R.P.M. X = .310
Y Strength Factor (Tables)
F Face Width in inches
R Speed in R.P.M.
P Diametral Pitch
N N° of teeth in pinion or gear
Z Zone factor (Tables)
K Pitch Factor (Tables) 3 DP = 2.4
2 DP = 1.7
1½ DP = 1.4

Main Gears:

Gear to be cast steel (B.S.S. 24, part 4, spec. No. 10)

Sc = 1,300 Sb = 18,000

Pinion—Forged steel, 1½ per cent nickel, 1 per cent chrome, flame hardened.

Sc = 5,000 Sb = 22,000

The horsepower to be transmitted is a ready known and we assume a pitch which is proportional to the size of the machine. This leaves us with one unknown, F. Transpose the formula and calculate F.

$$(\text{Strength})\ F = \frac{HP \times P^2 \times 126{,}000}{Sb \times X \times Y \times R \times N}$$

$$(\text{Wear})\ F = \frac{HP \times K \times P^2 \times 126{,}000}{Sc \times X \times Z \times R \times N}$$

H.P. to be transmitted allowing 25 per cent overload.

$$\text{H.P.} = \frac{148 \times 125}{100} = 185\ \text{H.P.}$$

Assume 2 D.P. Tooth 20° P.A. 16 teeth Pinion (solid with shaft)
96 teeth Wheel

Gear:

$$(\text{Strength})\ F = \frac{185 \times 4 \times 126{,}000}{18{,}000 \times .540 \times .660 \times 15 \times 96} = 10.1''\ \text{face}$$

$$(\text{Wear})\ F = \frac{185 \times 1.7 \times 2 \times 126{,}000}{1{,}300 \times .540 \times 1.7 \times 15 \times 96} = 46.1''\ \text{face}$$

It will be seen from the above figures, therefore, that the use of cast steel to the above specification is not permissible. The face width of 10.1 inches for strength would possibly be reasonable, but the face width of 46.1 inches for wear is of course out of the question and it becomes necessary to select some more suitable material.

We now select a forged steel rim of .55 per cent carbon which has an Sb value similar to the first material, but an Sc value three or four times as great as the cast steel. This is allowing for flame hardening after gear cutting.

Thus welding once more plays a most important part in the production of heavy duty machinery. The boss and H section arms of the gear wheel will be of commercial mild steel, while the rim will be of high class steel giving a tooth with a tough core of 45-tons to 50-tons per square inch tensile strength and a hard surface Brinell Number of from 400 to 500. This is of course an ideal com-

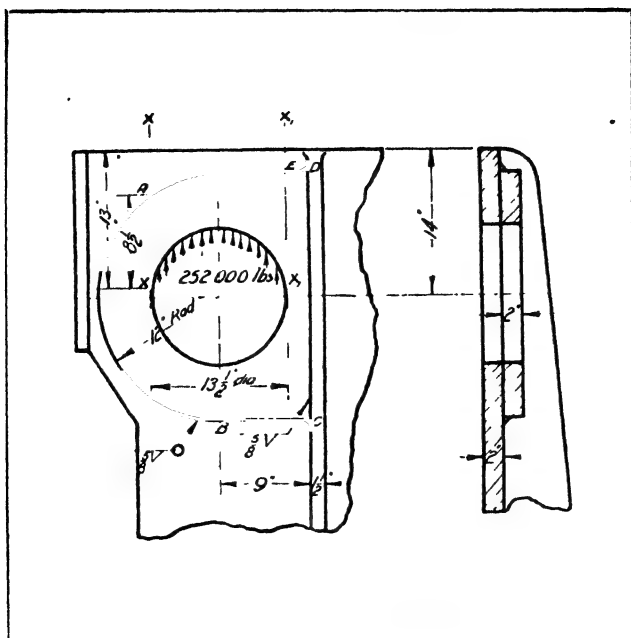



Fig. 6. Frame at main bearing.

bination for gear design The new figures for Sc and Sb are now 4,000 and 22,000 pounds per square inch respectively. A rough calculation shows that even with this steel, and utilizing a 2 DP tooth, the face width will still be too high as follows:

$$\frac{46.1 \times 1{,}300}{4{,}000} = 15'' \text{ Face}$$

Therefore it is necessary to utilize a 1½ DP tooth, in which case K will now equal 1.4 and P will now equal 1.5. The figures for the revised main gears are as follows:

Revised Main Gears:

Gear:

$$\text{(Strength) } F = \frac{185 \times 1.5 \times 1.5 \times 126{,}000}{22{,}000 \times .540 \times .690 \times 15 \times 96} = 4.45''$$

$$\text{(Wear) } F = \frac{185 \times 1.4 \times 1.5 \times 126{,}000}{4{,}000 \times .540 \times 1.7 \times 15 \times 96} = 9.25''$$

Pinion:

$$\text{(Strength) } F = \frac{185 \times 1.5 \times 1.5 \times 126{,}000}{22{,}000 \times .425 \times .66 \times 90 \times 16} = 5.9''$$

$$\text{(Wear) } F = \frac{185 \times 1.4 \times 1.5 \times 126{,}000}{5{,}000 \times .425 \times 1.7 \times 90 \times 16} = 9.38''$$

Thus, we come to the conclusion of the main gear requirements which are 16/96 teeth, 1½ DP, 20 degrees pressure angle, and 9¼-inch face.

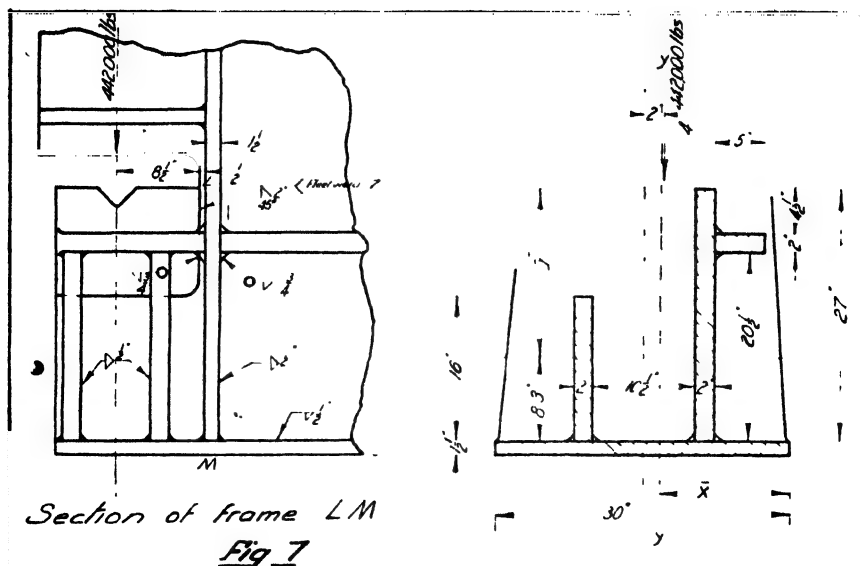



Fig. 7. Section of frame LM.

We now consider the first motion gears which are to have a ratio of 5 to 1, and we assume that the gear ratio will be 18/90 teeth, 3 DP, 20 degrees pressure angle.

1st Motion Gears:

Gear: 55% carbon steel flame hardened
Sc = 4,000; Sb = 22,000

Pinion: 1½ per cent nickel; 1 per cent chrome; flame hardened
Sc = 5,000; Sb = 22,000
X = .425 (90 R.P.M.); .310 (450 R.P.M.)
Z = 2
Y = .675 for pinion; .705 for wheel
K = 2.4
P = 3

Gear:

$$\text{(Strength) } F = \frac{185 \times 9 \times 126{,}000}{22{,}000 \times .425 \times .705 \times 90 \times 90} = 3.92''$$

$$\text{(Wear) } F = \frac{185 \times 2.4 \times 3 \times 126{,}000}{4{,}000 \times .425 \times 2 \times 90 \times 90} = 6.1''$$

Pinion:

$$\text{(Strength) } F = \frac{185 \times 9 \times 126{,}000}{22{,}000 \times .310 \times .675 \times 18 \times 450} = 5.62''$$

$$\text{(Wear) } F = \frac{185 \times 2.4 \times 3 \times 126{,}000}{5{,}000 \times .31 \times 2 \times 18 \times 450} = 6.65''$$

Therefore the assumption is found to be correct and the first motion gears will be 18/90 teeth, 3 DP, 20 degrees pressure angle, 6½-inch face.

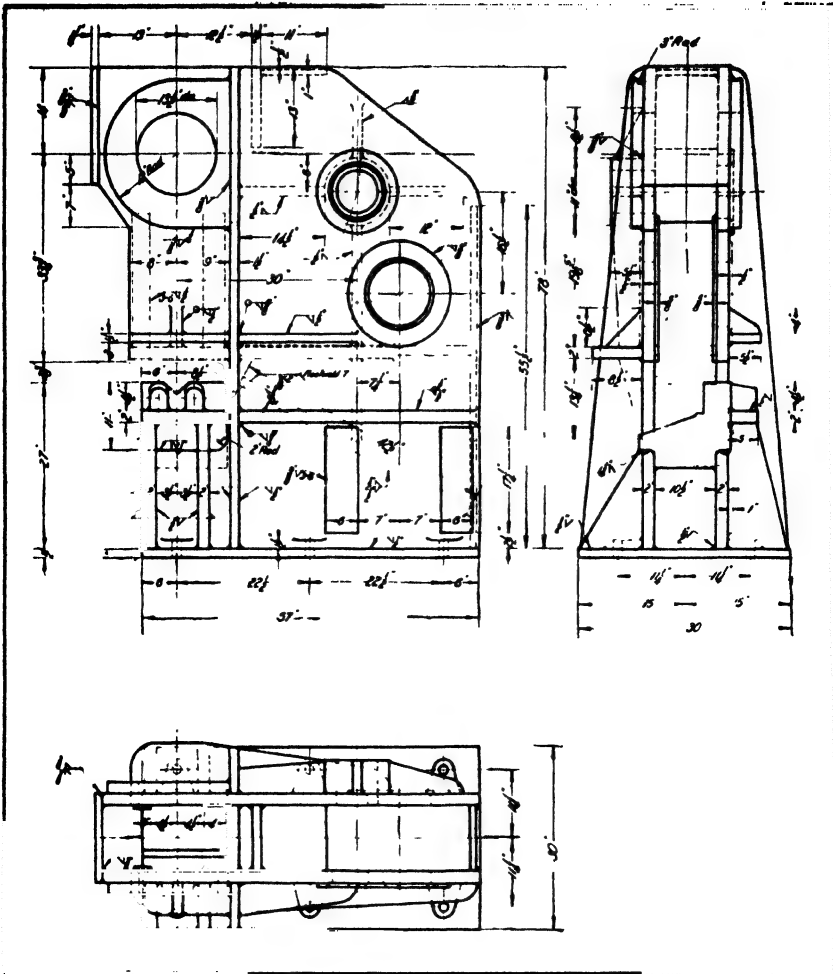



Fig. 8. Dimension drawing of shear.

So much for the gears. We now come to the design of the flywheel.

The principle of the flywheel is to store energy which is given out with a reduction of speed during the actual period of time in which the work is done, the usual practice in a machine of this type being to allow a 10/15 per cent speed reduction.

The energy expended by a flywheel while reducing in speed from V_1 to V_2 is as follows:

$$E = \frac{W (V_1^2 - V_2^2)}{64.32} = \text{ft.-lbs.}$$

where E = Energy expended in ft.-lbs.

V_1 = Initial velocity at mean radius of flywheel rim in ft. per sec.

V_2 = Velocity after reduction in speed in ft. per sec. In this case, the energy required to be expended by the flywheel = 30,720 ft.-lbs. with a reduction in speed of 15%.

In determining the weight of a flywheel, the weight of the rim only is to be considered, the weight of the arms and boss having very little effect.

We therefore assume a mean diameter which will look proportional to the machine and calculate the section of rim required.

We assume

$$D = 36''$$
$$E = 30{,}720 \text{ ft.-lbs.}$$
$$\text{R.P.M.} = 450$$

$$V_1 = \frac{2\ \pi \text{R.N.}}{12 \times 60} = \frac{2\ \pi\ 18 \times 450}{12 \times 60} = 70.7 \text{ ft./sec.}$$

$$V_2 = \frac{V_1 \times 85}{100} = 60.15 \text{ ft./sec.}$$

$$V_1^2 = 4{,}998.49$$
$$V_2^2 = 3{,}618.02$$

$$V_1^2 - V_2^2 = 1{,}380.47$$

From (6)

$$30{,}720 = \frac{W \times 1{,}380.47}{64.32}$$

$$W = \frac{30{,}720 \times 64.32}{1{,}380.47} = 1{,}430 \text{ lbs.}$$

Volume of steel required to give desired weight $= \frac{1{,}430}{.283}$ where .283 is weight of 1 cubic inch of steel

Volume = 5,050 cubic inches

$$\text{Area of cross section of rim} = \frac{\text{Volume}}{\text{Mean Circumference}}$$

$$\text{Area} = \frac{5{,}050}{36} = 44.6 \text{ square inches.}$$

We therefore decide on a flywheel rim section of 7.5″ × 6″.

The size of gears and flywheel having been determined the next stage is to make a preliminary design of the crank shaft to arrive at allowable bearing pressures for the various component parts before the frame can be designed with any degree of finality.

Calculations for Crank Shaft (Refer to Fig. 3):

$$\text{Sine } \theta = \frac{1.375}{14} = .0982$$

$$\theta \times 5^\circ\ 38'$$

$$P = \frac{F}{\text{Cos } \theta} = \frac{442{,}000}{.9953} = 444{,}000 \text{ lbs.}$$

$$\text{Pitch dia. of main gear} = \frac{96}{1.5} = 64'' \text{ dia.}$$

$$\text{Tooth Load} = \frac{444{,}000 \times 1.375}{32} = 19{,}100 \text{ lbs.}$$

Determine Reactions R_1 and R_2

Taking moments about R_1,

$$(442{,}000 \times 8.375) + (19{,}100 \times 26.25) = R_2 \times 16.75$$

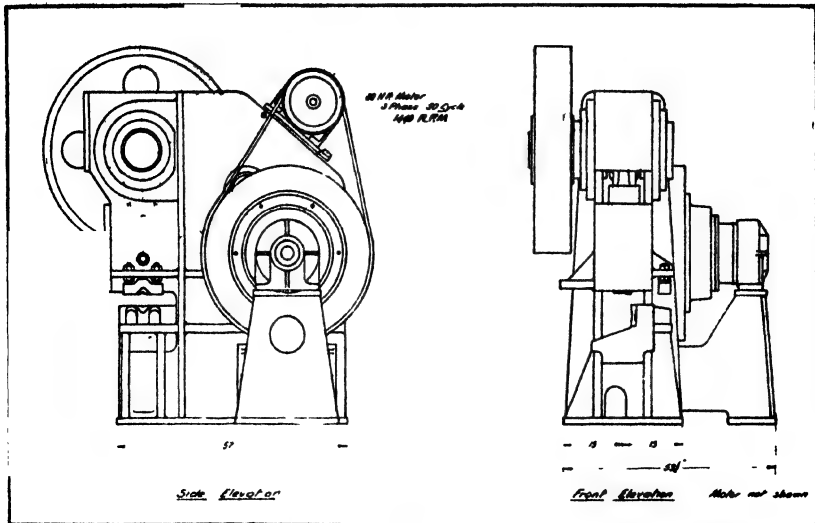



Fig. 9. General arrangement of shear.

$$R_2 = \frac{3,705,000 + 510,000}{16.75} = \frac{4,215,000}{16.75} = 252,000 \text{ lbs.}$$

$$R_1 = 442,000 + 19,100 - 252,000 = 209,100 \text{ lbs.}$$

Shaft for Bending and Torsion at A.A.:

$$Bm = 19,100 \times 5.25 = 100,300 \text{ in lbs.}$$

$$Tm = 19,100 \times 32 = 611,000 \text{ in lbs.}$$

$$Te = Bm + \sqrt{Bm^2 + Tm^2} \quad \text{.................... (Rankine)}$$

$$= 100,300 + \sqrt{100,300^2 + 611,000^2}$$

$$= 719,477 \text{ in lbs.}$$

$$Zp = \frac{\pi d^3}{16} = \frac{\pi \times 8.875^3}{16} = 137.4$$

$$fc = \frac{Te}{Zp} = \frac{719,477}{137.4} = 5,230 \text{ lbs. per sq. in.}$$

Shaft for Bending and Torsion at B. B.:

$$\text{Bending moment} = (252,000 \times 4.25) - (19,100 \times 13.75)$$

$$= 1,072,000 - 262,500 = 809,500 \text{ in lbs.}$$

$$Tm = 611,000$$

$$Te = 809,500 + \sqrt{809,500^2 + 611,000^2} = 1,828,400 \text{ in lbs.}$$

$$Zp = \frac{\pi \times 9.75^3}{16} = 184$$

$$ft = \frac{1,828,400}{184} = 9,920 \text{ lb. per sq. in.}$$

Shaft for Bending at C. C.:

Bending moment

Bm = 209,100 × 4.25 = 888,000 in lbs.

$$Z = \frac{\pi \times 9.75^3}{32} = 92$$

$$fc = \frac{888,000}{92} = 9,640 \text{ lb. per sq. in.}$$

From these calculations, it will be seen that the eccentric shaft must be manufactured from a steel which will give an allowable fc of 10,000 pounds per square inch with a factor of safety of 8, 3 per cent nickel chrome steel, suitably heat treated being finally selected.

Bearing Pressures—having arrived at the required dimensions, etc. of the eccentric shaft, the bearings and bearing areas are now considered. The loading is of an intermittent character and therefore comparatively high bearing pressures are permissible ranging from 5,000 to 8,000 pounds per square inch on the eccentric bearing and 2,000 to 3,000 pounds per square inch on the main journals. In this case, however, the eccentric bearing pressure is not of an excessively high order.

Eccentric bearing pressure = 442,000 = 4,620 lb. per sq. in.

while the Journal bearing pressures are subjected to a pressure of $\frac{252,000}{9.75 \times 8}$ = 3,040 lb. per sq. in.

As will be seen from the diagram shown on Fig. 3 we have assumed that the side plates will be approximately 10½-inch apart. This space must be sufficiently wide to (a) accommodate the first motion spur wheel and pinion having a face width of 6½-inches and (b) to accommodate the pitman and at the same time allow a sufficient bearing area on the little end of the pitman to keep the bearing pressures within a reasonable figure, and finally a third factor (c) also must be taken into consideration, this being the dimensions of the main crank shaft journals, which must be sufficiently long for good engineering practice, this point having a marked bearing on the design of the steel frame, the calculations for which are now taken out in some detail.

Frame—The general appearance of the machine is already known, both by experience and by usual engineering practice for this type of equipment and the preliminary design may now be taken out in the light of the data already accumulated, the preliminary sketch of the frame being detailed in Figs. 4 and 5 as follows.

It will be seen from Fig. 4 that the section O.A. (which is the section at which the maximum stress is likely to occur) is subject to three different stresses.

(1) The direct stress which is uniform over the whole section and is equal to $\frac{F}{A}$

(2) The bending stress due to F acting on the moment arm Y + 8.5″

(3) The bending stress due to F acting on the moment arm X. Refer to Fig. 5.

As stated above (1) results in a uniform ft_1 over the whole area (2) will create a maximum ft_2 along the face AB and a maximum fc_2 along the face CD (3) will create a maximum ft_3 at B and a maximum fc_3 at A.

By analysis it will be seen that the maximum ft will occur at the point B and the maximum fc will occur at the point D.

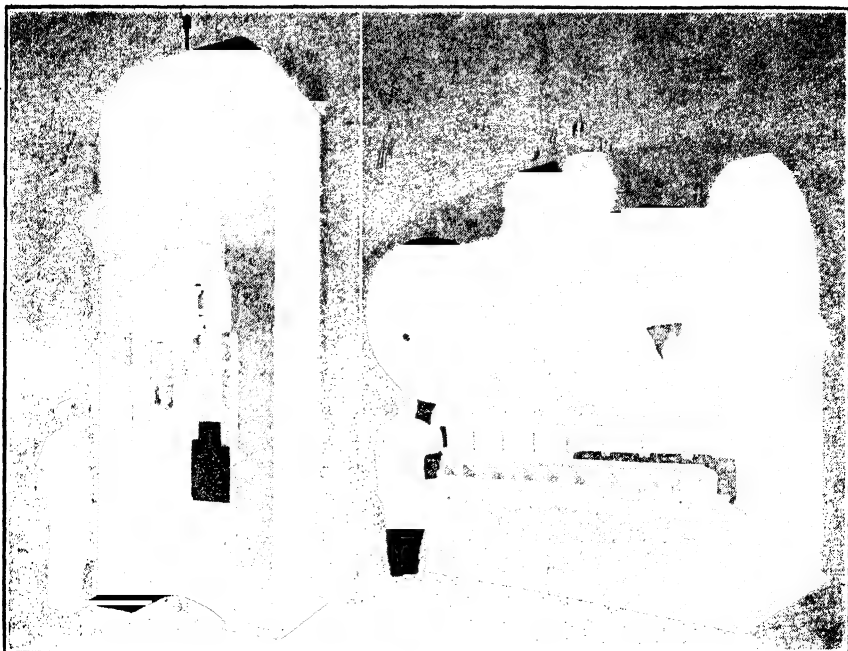



Fig. 10, (right). All-steel heavy-duty guillotine shears. Fig. 11, (left). All-steel crankless-type forging press.

Total stresses at various points:

A. $ft = ft_1 + ft_2 - fc_3$
B. $ft = ft_1 + ft_2 + ft_3$
C. $fc = fc_2 - (ft_1 + ft_3)$
D. $fc = fc_2 + fc_3 - ft_1$

Position of Neutral Axis YY.
Working from face AB as datum line

$$\overline{Y} = \frac{\Sigma \text{ first moments of sectional areas about datum line}}{\Sigma \text{ sectional areas}}$$

Σ = first moments of sectional areas about datum line.

$$= 2 \times 42\tfrac{1}{2} \times 2 = 170 \quad \times 21.25 = 3{,}615 \text{ in.}^3$$
$$2 \times 6 \quad \times 1.5 = 18 \quad \times 1.25 = 22.5 \text{ in.}^3$$
$$10\tfrac{1}{2} \times 1.5 = 15.75 \times 1.25 = 19.7 \text{ in.}^3$$
$$10\tfrac{1}{2} \times 1 = 10.5 \times 41.5 = 435.7 \text{ in.}^3$$

Σ Sectional Areas 214.25 in.^{2} Σ.F.M. Sect. Area = 4,092.9

$$\overline{Y} = \frac{4092.7}{214.25} = 19.1$$

Neutral Axis X.X will lie in the center of the section.
Moment of Inertia of Section about YY (by theorem of parallel axis).
Divide the section O.A. up into a number of smaller sections, a, b, c, d, e.

I_{YY} of whole section = Σ $\{$I each section about its own axis + area of each section $\times$ (moment arm of that section about YY)$^2\}$

$$I_{abc}\, YY = 22.5 \times 1.5^3 + 33.75 \times 17.85^2 = 11{,}966.32 \text{ ins.}^4$$

$$I_{2d}\, YY = \frac{4 \times 42.5^3}{12} + 170 \quad \times 2.15^2 = 26{,}373.54 \text{ ins.}^4$$

$$I_c \; YY = \frac{10.5 \times 1^3}{12} + 10.5 \times 22.4^2 = \frac{52,260.87}{43,600.73} \text{ ins.}^4$$

$$\text{Section Modulus } Z_{YY} = \frac{I}{Y} = \frac{43,600}{19.1} = 2,282 \text{ in.}^3$$

Moment of Inertia about XX (by theorem or parallel axis).

$$I_{ac} \; XX = \frac{3 \times 6^3}{12} + 18 \times 10.25^2 = 1,944 \text{ in.}^4$$

$$I_{2d} \; YY = \frac{85 \times 2^3}{12} + 170 \times 6.25^2 = 6,691.6 \text{ in.}^4$$

$$I_{be} \; XX = \frac{2.5 \times 10.5^3}{12} = \frac{240.7 \text{ in.}^4}{8,876.3 \text{ in.}^4}$$

$$\text{Section Modulus } Z_{xx} = \frac{8876.3}{13.25} = 670 \text{ in.}^3$$

Direct Tensile Stress

$$= \frac{F}{\text{Area of cross section}}$$

$$= \frac{442,000}{214.25}$$

$$= 2,062 \text{ lb. per sq. in.}$$

Stress Due to F acting on moment arm Y.

$$Bm = 442,000 \times (8.5 + 19.1) = 442,000 \times 27.6$$

$$ft = \frac{Bm}{Z_{YY}} = \frac{442,000 \times 27.6}{2282} = 5,340 \text{ lb. per sq. in.}$$

Stress due to F acting on moment arm X.

$$Bm = 442,000 \times 2$$

$$ft = \frac{Bm}{Z_{xx}} = \frac{442,000 \times 2}{670} = 1,320 \text{ lb. per sq. in.}$$

Total Tensile Stress at B.

= 2,062
5,340
1,320

8,722 lb. per sq. in.

Refer to Fig. 6.

Shear Stress on Sections XX and $X_1 X_1$

Area to be sheared = 2 × 13 × 2 = 52 sq. ins.
2 × 8.5 × 2 = 34 sq. ins.

86 sq. ins.

$$fs = \frac{252,000}{86} = 2,930 \text{ lb. per sq. in.}$$

There are three main ways in which the frame could rupture,

(1) By shear as shown above

(2) By shearing the 2" plates of the frame itself and the weld ABCDE of which A to B and C to D is parallel to line of force and BC and DE are transverse to the line of force.

or (3) By bearing stress between the frame and C.I. bearing housing which is let into the frame.

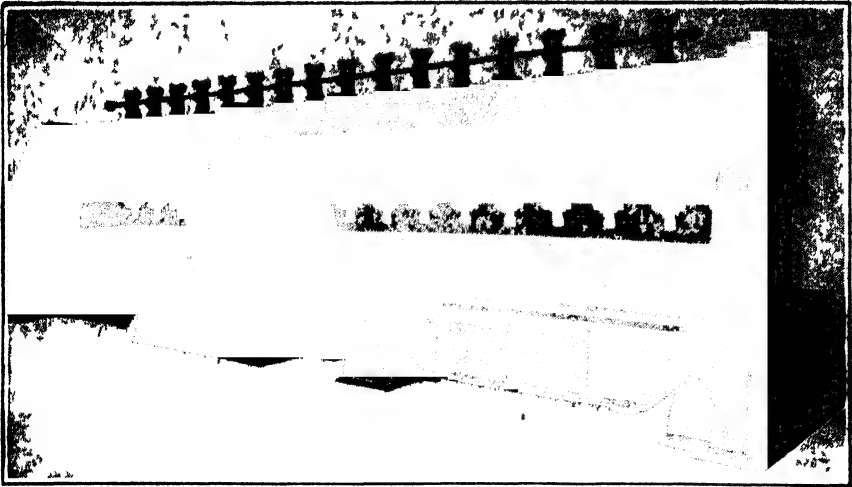



Fig. 12. All-steel plate-edge planing machine.

(1) Has already been dealt with above.

(2) Amount of weld in longitudinal shear

A to B = 29½″
C to D = 24″

Weld in longitudinal shear = 53½″

Amount of weld in transverse shear

B to C = 9″
D to E = 2¼″

Weld in transverse shear = 11¼″

Allowing transverse weld 30 per cent stronger than longitudinal weld, determine the amount of transverse weld which would be required to give the same strength as the longitudinal weld.

$$\frac{53.5 \times 100}{130} = 41.2''$$

Equating ultimate strength of the reinforcing plate in shear through section XX and $X_1 X_1$ against the ultimate strength of the weld, we will determine the size of weld required.

$U_s \times$ Area of Section = Ultimate shear strength of weld $\times$ length of weld.

$$44{,}000 \times 2(8\tfrac{1}{2} + 10\tfrac{1}{2}) = U_{ws} \times 41.2 + 11.25$$

$$U_{ws} = \frac{44{,}000 \times 38}{41.2 + 11.25}$$

$$= 31{,}920 \text{ lb. per } 1''$$

Ultimate strength of weld metal using shielded arc = 60,000 lb. per sq. in.

$$\text{Therefore size of weld required } \frac{31{,}920}{60{,}000} = \text{Say } \frac{5}{8} \text{ fillet}$$

(3) Bearing Stress between C.1. Bearing housing and frame

$$= \frac{\text{Load}}{\text{Projected Area}} = \frac{252{,}000}{13.5 \times 4}$$

$$= 4{,}650 \text{ lb. per sq. in.}$$

Refer to Fig. 7.

Determine Y.

$$2 \times 27 = 54 \times 13.5 = 730$$
$$2 \times 16 = 32 \times 19 = 608$$
$$2 \times 5 = 10 \times 5.5 = 55$$
$$1.5 \times 30 = 45 \times 27.75 = 1{,}245$$

141 in.^{2} 2,638 in.^{3}

$$\bar{Y} = \frac{2{,}638}{141} = 18.7$$

Determine X.

$$2 \times 27 = 54 \times 8.75 = 473$$
$$2 \times 16 = 32 \times 21.25 = 680$$
$$2 \times 5 = 10 \times 5.25 = 52.5$$
$$1.5 \times 30 = 45 \times 15 = 675$$

141 1,880.5

$$\bar{X} = \frac{1{,}880.5}{141} = 13.35''$$

From the above it is seen that the line of force almost coincides with the axis YY and therefore twisting is almost eliminated.

Calculate for pure bending due to the force F acting on moment arm $8\frac{1}{2}''$.

I_{xx} of whole section

$$I_{cxx} = \frac{2 \times 16^3}{12} + 32 \times 3^2 = 684.5 \text{ in.}^4$$

$$I_{bxx} = \frac{30 \times 1.5^3}{12} + 45 \times 9^2 = 3{,}653 \text{ in.}^4$$

$$I_{axx} = \frac{2 \times 27^3}{12} + 54 \times 5.2^2 = 4{,}740 \text{ in.}^4$$

$$I_{dxx} = \frac{5 \times 2^3}{12} + 10 \times 13.2^2 = 1{,}745 \text{ in.}^4$$

10,822.8 in.^{4}

$$Z_{xx} = \frac{10{,}822}{18.7} = 578 \text{ in.}^3$$

$$Bm = 442{,}000 \times 8.5''$$

$$ft = \frac{Bm}{Z} = 442{,}000 \times 8.5 = 6{,}500 \text{ lb. per sq. in.}$$

Before web d (in section) can be relied on for strength as we have done above, it must be welded to the upright web in such a way that the ultimate strength of the weld equals the ultimate strength of the web so that it will not pull away.

Length of weld = 12″

Area of cross section in tension = 10 sq. ins.

Ultimate tensile strength of steel = 55,000 lb. per sq. in.

$$10 \times 55{,}000 = 12 \text{ x } 3$$

where x is the required strength of weld per inch.

$$x = \frac{10 \times 55{,}000}{12} = 45{,}800 \text{ lb. per sq. in.}$$

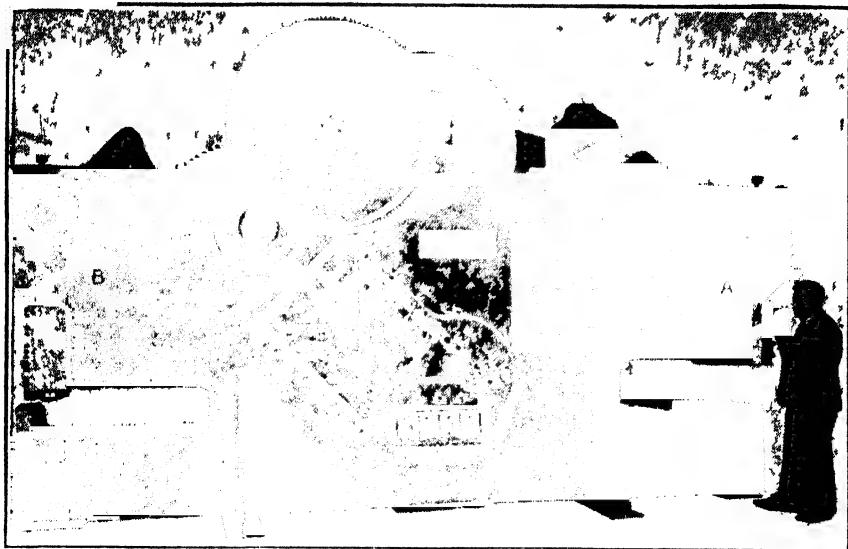



Fig. 13. All steel heavy duty punching and shearing machine.

Allowing ultimate strength of weld metal (Shielded Arc) = 65,000 lb. per sq. in.

$$\text{Size of weld required} = \frac{45{,}800}{65{,}000} = .7''$$

$$\text{Allow } \frac{3}{4} \text{ fillet weld.}$$

The foregoing notes indicate the procedure adopted by the writers' company in the design of a machine frame The resultant machine is efficient and strictly utilitarian and yet is very pleasing in appearance as is illustrated in the attached photograph, (Fig 15), of the completed machine

As pointed out in the introductory remarks to this paper, the writers' company has not placed the question of cost in an all important position, and yet as the following figures show, the cost of the above machine frame is very attractive in comparison with a similar machine utilizing a cast steel frame We specify a cast steel frame in order to give a truer comparison, as a cast iron frame for a machine of this type would hardly be suitable owing to the great shock loading to which it would be subjected, and in any case the weight of such a frame, with the heavy body of metal required to withstand the stresses set up, would be excessive and no cheaper than the cast steel frame

The cost of fabricating the frame of the machine analyzed was as follows

Analysis of Cost Taken from Actual Cost Records Based on Australian Prices—Steel used in frame based on average cost of 4-cents per lb Overhead Charges based on 120 per cent on productive labor and 10 per cent on material Oxygen based on $1 02 per hundred cubic feet Cast Steel insert used in frame charged at 16-cents per lb

Materials Cost.

NOTE:
The conversion of Australian money into dollars and cents is based on par values: 2 American Cents = 1 Australian Penny

Gross weight of steel utilized in frame, allowing 15 per cent for scrap = 11298 lbs. @ 4 cents =	$451.92	
Plus 10 per cent Overhead Loading	45.19	
	497.11	
Less Value of Scrap Recovery	11.86	
Total		$ 485.25
Cost of Electrodes	52.80	
Plus 10 per cent Overhead Loading	5.28	
Total		58.08
Cost of Oxygen	38.40	
Plus 10 per cent Overhead Loading	3.84	
Total		42.24
C/f		585.57
Cost of Coal Gas—(negligible, say)		5.00
Total Material Cost Including Overhead Charges		590.57
Labor Cost		
Welding Productive Labor	$110.26	
Plus Overhead Loading 120 per cent	132.31	
Total		242.57
Profile Machine Operating Productive Labor	31.24	
Plus Overhead Loading 120 per cent	37.49	
Total		68.73
Marking Off Productive Labor	35.84	
Plus Overhead Loading 120 per cent	43.01	
Total		78.85
Apprentice Labor Productive Labor	15.00	
Plus Overhead Loading 120 per cent	18.00	33.00
Total Labor Cost including Overhead Charges		423.15
Total Material Cost including Overhead Charges		590.57
		$1013.72

Thus, it will be seen that the total cost for the fabrication of this frame works out at 10.9 cents per pound net, and in comparison we give the estimated cost of a similar cast steel frame based on a very conservative estimate.

The cast steel is taken as costing in Australia 16 cents per pound and we have assumed a weight of 9,943 pounds which is the same weight as the fabricated frame less the 15 per cent which is allowed for scrap (actually the weight would probably be considerably greater than this owing to the necessity to consider such casting problems as flow of metal, etc.)

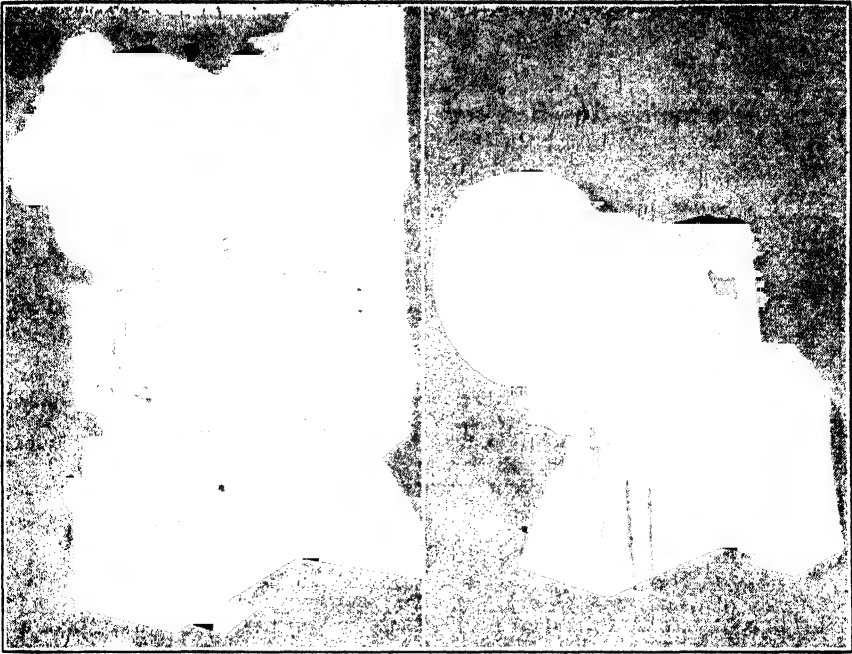



Fig. 14, (left). End view of shearing machine shown in Fig. 13. Fig. 15, (right). All-steel heavy-duty open-ended cropping shear.

This works out at	$1590.88	
Estimated cost of pattern	380.00	
Total Cost of Cast Steel Unit		$1970.88
Total Cost of Fabricated Unit		1084.11
Balance in favor of the Fabrication		$ 886.77

This is a very substantial saving representing 44.66 per cent on the cost of the cast steel frame, though the pattern cost would of course be liquidated in the first machine, and if any subsequent orders are received for a similar unit, the saving would not be so substantial but would still represent 31.8 per cent.

In conclusion, may we stress again the value of welding as applied to machine frames in Australia. Summarized, the advantages are: (1), probable cheaper construction; (2), greater reliability; (3), availability, without fear of loss through enemy action; (4), increased efficiency due to greater rigidity thus leading to reduced operating costs; (5), the clean, modern appearance assisting in the making of sales; (6), faster production times; (7), freedom from loss through hidden defects; (8), the elimination of pattern cost and pattern storage; (9), the greater flexibility of design enabling the manufacturer to produce the exact machine required by the purchaser for his particular purpose.

These nine reasons must surely convince the most skeptical that the welding industry has made a very marked contribution to the social structure, even in times of peace, and how much more so is this obvious in times of war, when maximum production is a sacred duty.

Chapter II—Bed for Milling Propeller Blades

By P. W. Martin

Secretary and Chief Engineer, Smalley General Co., Bay City, Mich.

P. W. Martin

Subject Matter: Cost estimate indicates saving by welding of 15 per cent over cast iron bed. Welding made possible delivery 4 weeks earlier than previous cast iron beds. Size of bed 16-feet by 2-feet 4-inches, weight 4,500 pounds, cost $1,640. The bed was heat treated before machining and stood up well during handling. Paper describes in considerable details all steps of manufacture such as assembling, welding, machining, planing, drilling, topping, etc. It was possible to provide larger openings than in a cast iron bed and obtain more space inside for motor and wiring.

There has been a great deal of discussion for and against steel beds for machine tools. Some claim that the fabricated beds vibrate, causing chatter and noise and also that they are not rigid enough to hold their shape and spring under the load. Another claim which has been made is that they do not retain their shape. This latter point is very important, particularly in a precision machine for if distortion occurs through seasoning, it is thrown out of line.

On the other hand many claim that the steel beds are lighter, stronger and do not distort through seasoning. It is also claimed that they are amply rigid and are not subject to cracking which sometimes occurs in a cast iron bed. A cast iron bed will sometimes crack in heat treatment and they have been known to crack after they have come from the foundry before heat treatment. Internal stresses are sometimes caused by uncovering the castings improperly or removing them from the sand too soon.

Another difficulty encountered in cast iron beds is in obtaining the proper mixture. There is a popular demand at the present time for close-grained hard iron. This iron takes a higher polish than the old open grain iron and the hardness gives it longer wearing qualities. The thickness of a casting usually varies considerably in different parts. In many places the wall can be much thinner than in other places and these mixtures of hard iron are liable to chill and become very hard and brittle at the thinner points when the hardness is just about as desired at the heavier points. In a machine with moving members the ways are usually heavy, while some of the other parts of the bed can be of much lighter section. The result is, if considerable care is not taken, the lighter sections which have some machined surfaces are too hard and brittle to be worked.

Another point about a cast iron bed, which is by no means always present, is the difficulty of obtaining the desired shape due to intricate coring. In a fabricated bed this can usually be obtained much easier and there is no liability of loss as in a casting. Another advantage of a steel bed is that it has greater strength and therefore is not subject to breakage.

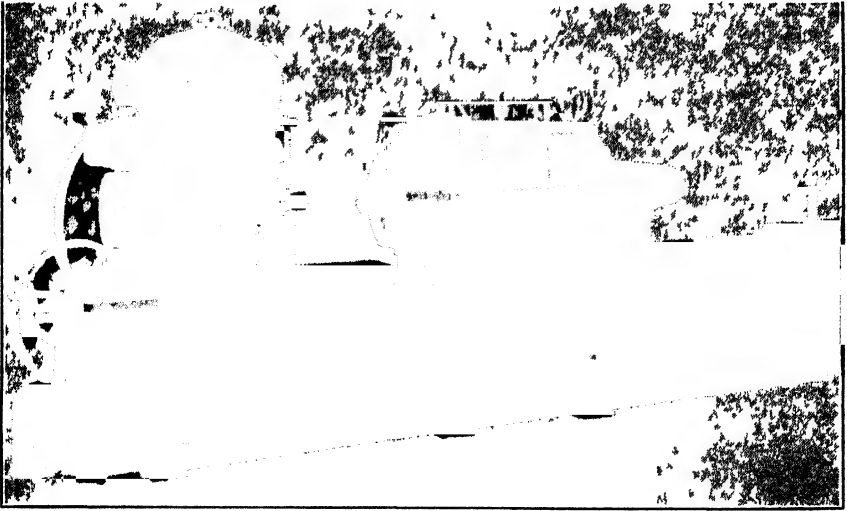



Fig. 1. Rear view of thread miller with propeller blade in place.

It is a well known fact that cast iron has a tendency to dampen vibration. It also has a tendency to wear better than soft steel and has less tendency to cut This being the case it is comparatively easy to provide cast iron ways for a bed by bolting them to a steel foundation This has an added advantage over the cast iron bed in the fact that the ways can be renewed when worn or badly cut

A short time ago we received a contract for several special thread millers These were for the purpose of milling propeller blades, and not only did they have to have a large diameter spindle but they had to have ways on each side of the main spindle bearing On one side our milling head operated and the other side was used to true up the opposite end of the propeller blade so that it would rotate on its true axis These ways had to be in line

There are several features of this machine which are quite different from our standard machine on which we have been using cast iron beds One of the principal differences was the large diameter hollow spindle After considering the matter from various angles we decided to use a steel bed We could get that quicker, and that was an important element Also we figured that, for the limited number at any rate, we would save expense because of the saving in the cost of the pattern, boxes, etc We therefore worked up the design which is shown in the enclosed prints and photographs of the finished machine

We decided to use half inch plates in the sides of the machine, (See Figs 1, 2 and 3), and as we wanted these to remain at a constant width we cast steel bearings for the spindle and used them for separators The bearings were machined before placing them in the bed leaving 1/16-inch on the bore and on the end for finish after welding together This machine work was much easier to perform on the boring mill than after the bearings were welded in place We made a mandril which secured the two castings with the proper spacing and prevented their shifting in welding Wings were provided on each casting which, on being finished, made the proper spaces for the side plates and also braces for the bed The castings were then, of

course, solidly welded into the structure. On the right end of the bed the milling head was mounted and therefore this end had to be very rigid.

In thread milling we get severe side thrusts as well as down thrusts and also a tendency to vibrate or chatter due to the intermittent action of the cutter. We therefore decided to place the 1½-inch strips along the top of both extensions and these would afterwards be planed off and the ways bolted to them. Between these ways we needed a trough to catch the coolant and chips and direct them to a pan down underneath. We therefore placed heavy separator plates at 18-inch intervals in the right hand section and they extended clear to the bottom in some cases and part way down in others. These not only provided a series of braces but broke the side plates up into small square sections thus reducing the liability to vibrate. These plates were cut out with a U-shape gap in the center which formed the base for the trough and thus they were permitted to run up to the under side of the top plates so they could be welded to them. A U-shape plate was then placed in the trough but the edge did not come up to the top plate but left a space of approximately 2½-inches between the top plate and the top edge of the trough. This was to permit access to the bolts which were used to hold the ways in place. They will be mentioned later.

On the bottom of the right hand end was placed a plate which formed a pan into which the coolant was directed and stored. The rear side plate had two arched openings cut in it to give access to the pan for cleaning, and the edges of the bottom plate were bent up on an angle of 45 degrees to a height of 4½-inches. At the clean-out points there were lips placed on the outside of the pan so as to enable the helper to place the pan under the lip and prevent the oil dripping on the floor. Running down from the bottom of the trough was a chute. Under this chute and level with the top of the pan were placed two angle slides. These carried a pan 4-inches deep. The pan was punched full of ¹⁄₁₆-inch holes to permit the coolant to run out but to retain the chips. This arrangement permitted the helper to draw the pan out and dump it. It also prevented the necessity of cleaning out the bottom of the pan at frequent intervals. The plate under the right hand end of the main bearing went clear to the bottom thus tying the whole bed together and forming the end of the pan.

On the left hand end of the bed we put the same top plates, but as it was not necessary to have the same rigidity there, we cut away the back plate and thereby provided an opening into which a 7½ horsepower four speed motor could be inserted. This opening was tied together at the top and bottom and a tilting base was placed inside for the support of the motor so it could be adjusted to tighten the belt. There was also an opening in the front plate to provide accessibility to the screws which operated the tilt of the table. A shallow trough was placed between the ways at this end with a sump up against the bearing which drained into the pan at the other end. At the extreme left end a door was provided which gave a small storage space for tools.

Between the two end plates under the bearings was placed a tilted plate. This was welded in tight and a hole placed flush with the plate so that the drip from the bearings would run down into the pan. This prevented the oil from getting onto the floor. There were two other openings placed beneath this drain plate. One for the reception of the pole changing switch and the coolant pump switch inside. The other hole was to enable the electricians to wire the motor. Louvre covers were placed over all the openings. Around the bottom of the bed were welded steel feet. These were

Fig. 2. Front view of thread miller.

provided with holes for anchor bolts and leveling screws The feet were placed below the pan so that in planing we did not have to carry the cut all the way across the bottom but simply along the lines of the feet

The main spindle was driven by a train of gearing which was mounted in a fabricated gear box This box was placed on the back of the machine after assembling The power shaft came through the end plate of the box so that the V belt sheave could be placed thereon and be driven by an inclined belt from the motor The gear box was made up of steel because a cast iron box would require rather complicated coring

In machining this bed we turned it on its side and planed off the feet We then turned it right side up and planed off the retention for the caps on the steel bearings That gave us a starting point for the distance of 15 inches from the center of the bearing to the upper surface of the top plates These were then planed off using a shear tool for the finishing cut This left a smooth surface for scraping The edge of the opening which had been formed by welding in 1/2- by 1-inch bars were then planed off as were also the strips welded on the back for the reception of the gear box The bed was then sent to the horizontal boring and milling machine to finish the extreme right and left hand ends Extreme care was taken to get the proper lineup between the right and left hand ends The top plates were then scraped into surface plates and the top plates drilled with a jig In planing these we cut a 1/2- by 1/4-inch keyway down the full length of the top plates.

The cast iron ways which were 1 1/2-inches thick made of a hard close grained iron had been previously planed to size and scraped The bottoms of the plates were then drilled with blind holes and tapped Then we placed studs in the ways and a key in the center where there was a keyway to match the one in the bed. Next the ways were bolted down. The opening which had been left between the top edge of the trough plate and the bottom of the top plate permitted the assemblers to reach the nuts that were placed on the studs On applying the face plate to the top of the ways it was

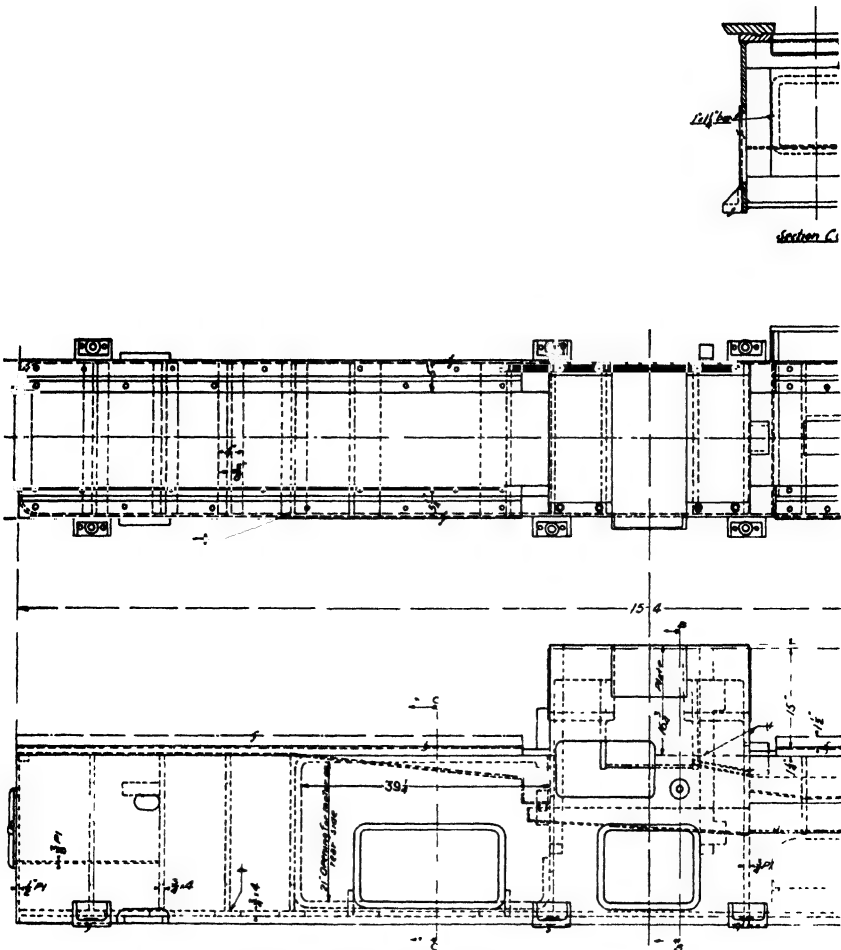
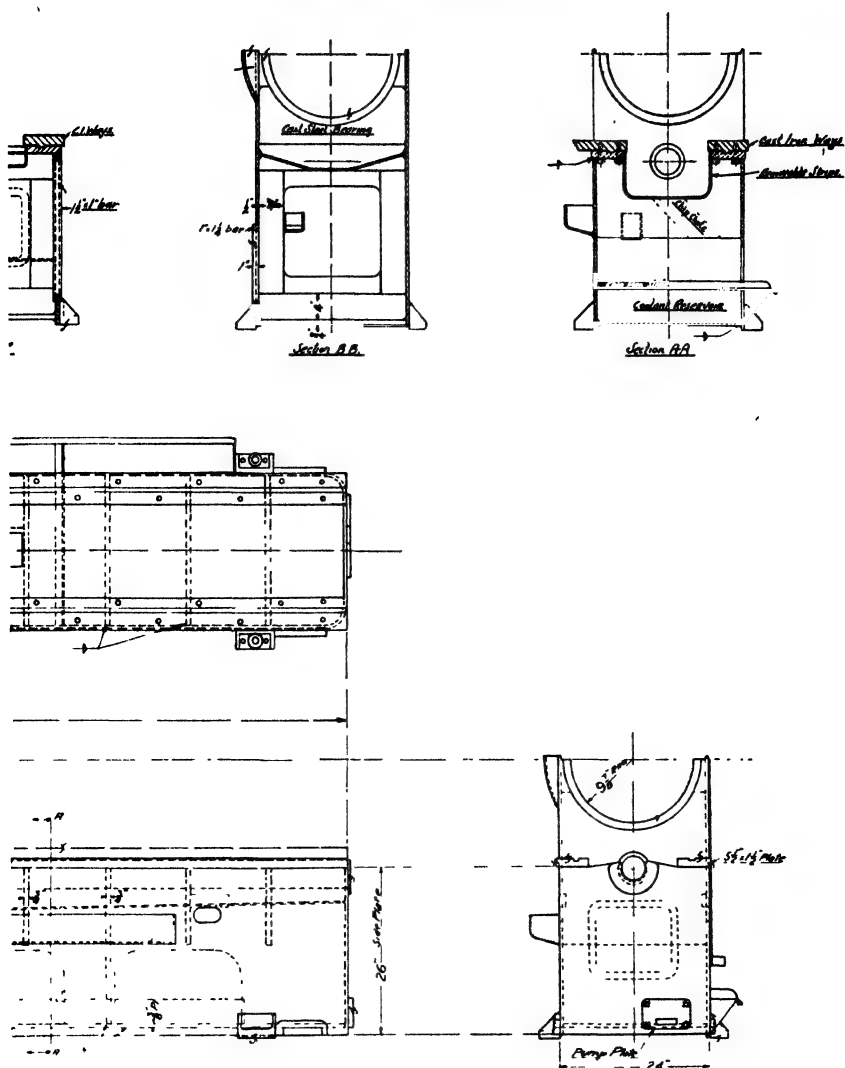



Fig. 3. Details, fabricated steel bed.

found that there was very little work necessary to true them up. In fact the time required to scrape and assemble the ways on the bed was not as long as that required to scrape in a similar cast iron bed.

The greatest inaccuracy of such an operation is in the bed itself and with a steel bed the distortion due to seasoning was less than the distortion in a cast iron bed and the steel bed was softer and could be worked faster.

It is necessary of course to heat treat both steel and cast iron beds before finish machining to relieve the internal stresses which later cause distortion if not removed. The bed was then taken to the boring mill for the boring operation. There the 1/16-inch which was left for finish was removed, thereby insuring perfect alignment and proper size. The ends were also faced.

In handling the bed for these various operations after scraping there

is a liability that the bed will spring out of line if not sufficiently rigid. When the bed was brought back to the assembly floor we found that it was absolutely in line. We had been warned by some that unless we gave it a second heat treatment after rough machining it would distort and get out of line in handling. After putting in the bronze bushings we handled it again with slings and still had no difficulty.

On completion and test we found that the steel bed functioned perfectly. There was absolutely no vibration or noise and on examining the threads produced there was no unusual spring. We took exceptionally heavy cuts with the form milling cutter with the same results stated above.

The weight of the steel bed before machining was 4500 pounds. It was 16-feet 8-inches long and 2-feet 4-inches wide.

In planning the cutting of the steel the side plates were cut 26-inches

wide so that the weld with the bottom plate was on the bottom and did not show. In the center at the bearings an extra plate 16¾-inches wide was welded onto the side plate to cover the upper part. This was more economical in cutting than it would have been to make it all of one plate 43½-inches wide. The side plate was beveled so that we had a good weld after grinding smooth. The side plates were rounded at the end corners and the end plates welded in between. The heavier cross plates were flame cut and their width maintained exactly. We had a cutting machine for this work.

The cost of the steel bed was as follows:

Welded bed 4500 lbs. including heat treatment	$ 893.00
2 bearing castings bottom half 352 lbs. @ .12¢ lb.	41.64
Machining castings, 20 hrs. @ $2.50 per hour	50.00
Planing, 60 hrs. @ $4.00 per hour	240.00
4 Ways 1483 lbs. @ .11 per lb.	163.13
Planing ways ready for scraping, 26 hrs. @ $4.00	104.00
Drill and tap ways, 3 hrs. @ $2.00	6.00
Scrape bed drill and fit ways, 60 hrs. at $2.00	120.00
Final scrape after attaching ways, 10 hrs. @ $2.00	20.00
	$1637.77

In welding it was possible to keep the bed very straight so we were not bothered in machining it.

This steel bed had several advantages over the cast iron bed. First, the ways are renewable. If in time these machines get badly scored or require truing up, due to wear, new ways can be put on them. Or, if this wear is not too much, a 1/16-inch shim of steel can be placed under them thus raising the ways and they can then be planed off to the same height they formerly were and be scraped. Furthermore the bed is much stronger than the cast iron bed. In handling the machine in the plant where they were installed, they placed slings through the oval holes provided at each end and picked up the machine. When the riggers did this they questioned whether it would be safe to pick it up by the end in that manner. The machine was very quickly handled in this way and did not spring. Later they raised the machine by placing slings in the recesses provided for jacks and raised it with one hook. They were again skeptical as they had been handling some other cast iron beds of equal length and they had to space slings very differently. The fact that the beds had not sprung in any way was shown by the fact that they leveled up very easily and accurately.

In contrast with this steel bed we give below a comparison of the cost of a cast iron bed with solid ways and one with removable ways. The latter, of course, is the truest comparison. The figures given are obtained by comparing the actual time of machining our standard No. 27MB1 bed which was almost exactly half the size of the steel bed when considering the ways. I think these costs are very accurate. If anything they are on the favorable side for the cast iron bed.

A cast iron bed similar to the one we formerly used could not have been made up as advantageously as the steel one because:

(a) It would not have been advisable to have such a large opening in the side for the motor because of weakening a cast iron structure. We had to have a large motor, and if placed outside it would have occupied valuable floor space, been in the way and would have been unsightly.

(b) We could not have obtained the space inside for wiring, etc. and at the same time obtained the pan with the same ease.

(c) The cast iron bed with solid ways is difficult to repair, as mentioned above.

From the above it will be seen that the steel bed possessed many advantages which cannot be summed up in dollars and cents.

Cost of cast iron bed with solid ways

Pattern \$735.00, 1/12 of same	\$ 61.25
Box \$220.00, 1/12 of same	18.33
Casting weight 6550, @ .10½	687.75
Grinding surface for painting, 10 hrs. @ \$1.75	17.50
Heat treatment, .01 per lb., wt. 6550	65.50
Steel pan	160.00
Legs, including attachment	120.00
Planing, 123 hrs. @ \$4.00 per hr.	492.00
Scraping, 108 hrs. @ \$2.00 per hr.	216.00
	\$1838.33

With a cast iron bed equipped with removable ways the price would run as follows:

Pattern \$735 total 1/12 of same	\$ 61.25
Box \$220.00 1/12 of same	18.33
Casting weight 6550 @ .09½ (soft iron cheaper)	622.25
Grinding surface for painting 10 hrs. @ 1.75	17.50
Heat treatment .01 per lb. wt. 6550	65.50
Planing 112 hrs. @ 4.00 per hr. (soft iron faster)	448.00
Steel pan	160.00
Legs and attaching	120.00
4 cast iron ways 1483 @ .11 per lb.	163.13
Planing ways ready for scraping 26 hrs. @ 4.00	104.00
Drill and tap ways 3 hrs. @ 2.00	6.00
Scrape bed, drill and fit ways 60 hrs. @ 2.00	120.00
Final scrape after attaching ways 10 hrs. @ 2.00	20.00
	\$1925.96

As this casting could be of soft iron I have put the price at .09½ per pound and as it would machine more easily I put the planing time at 11 hours less.

In the case of both the cast iron beds we figured 1/12 of the pattern expense and 1/12 of the flask expense. There were 12 machines in this lot and while it is a special machine now it can easily be standard machine for this particular work in the future. However some basis for figuring had to be adopted and taking 1/12 the expense seemed reasonable especially inasmuch as pattern upkeep would help equalize the charge.

We specified a steel pan in the cast beds because our experience has been that often a bed with the pan cast as an integral part proves to be defective and leaks and often results in the loss of the castings.

Cleaning expense was put into the cast iron bed because it is an item which often seems higher than I have given it. The steel beds were welded

by a contractor and he ground down any welds so that we could apply our paint without so much preparation. We could also omit the filler and the difference in painting the two machines would be considerable although not considered.

Where similar operations, like boring out the heads, were of equal length we did not consider them. Another thing we omitted mentioning was the caps. They would be the same in each case.

We did not carry out the design of the cast bed to completion because we saw we were going to have awkward situations in coring, etc. in order to get the clean, smooth outward appearance we desired. We have also previously mentioned other considerations. The price of the welded steel gear case was left out of both beds because we would have followed the same construction in either case. The coring in a cast case would have been very difficult and expensive. By making it of steel we obtained a very strong and rigid case with bearing supports wherever we wanted them and at the same time it was lighter than cast iron.

When the machine was started on its work we took some very heavy cuts and crowded the feed, but in the pieces that were of the proper hardness, there was no chatter. This was true in both form milling and thread milling. At no point was there any vibration of the sides nor any noise. Later we had some parts which were extremely hard. They Brinelled nearly 400. The shank of the propeller blades projected beyond the chuck about 10-inches and we got a very bad chatter. However, all the vibration was in the piece and the cutter. There was an entire absence of vibration in the chuck and the milling head. Out at the end of the work the vibration was however very noticeable thus showing that it was the work that sprung and not the machine. In designing the cutters we specified a 1½-inch bore but they were made up with a 1¼-inch bore. The weakness of the arbor was a contributing cause to the chatter. At no time was there any unusual noise or vibration noticeable in other parts of the machine. The firm getting the machine was very much pleased with it and naturally we were very much pleased with its performance. The purchaser commented very favorably upon the appearance of the machine as a whole.

To sum up—our experience with the steel bed was most gratifying. The total weight of the machine was no more than our standard machine which has no extension of ways on the back end of the machine. It showed a very high degree of stability and rigidity. It was very quiet in operation and its appearance was all that could be desired. It was clean and sufficiently streamlined to meet the demands of the most critical. As stated earlier in the paper, we were very strongly advised by a number of people, including some machine tool manufacturers, against going to a steel bed. Some said it would be noisy, some that it would spring and chatter and others claimed that it would not retain its accuracy, but would distort. None of these prophecies came true and we have had the first machine running for several months. Another point which we think we have demonstrated is that one heat treatment after the welding was completed, was sufficient.

As usual we can see places where we would do differently next time. For instance we would make the bearing of 1½-inch bars either bent to shape or cut from solid. This would be cheaper, quicker and do just as well. We would also cut out two of the 4 x ¾ squares braces or panels in the rear end as we are convinced they are unnecessary.

The advantages of the steel bed over the cast iron beds can be summed up as follows:

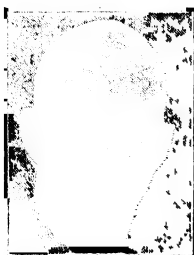
	Steel bed	Cast Iron Beds Solid ways	Removable ways
Cost of each bed	1637.77	1838.33	1925.96
Additional cost over steel bed		200.56	288.19
Percentage saved by steel bed		10.91%	14.97%
Saving in 12 machines		2406.72	3458.28

With the steel bed we estimate that we delivered the first machine about four weeks sooner than we would have with the cast iron and all succeeding machines have come through faster. This saving in time is important in this National emergency. Also as stated before our design was much better not only in appearance but in arrangement and accessibility. The elimination of the risk of losing a casting is also worth considering.

The bed was assembled and welded by the Valley Welding and Boiler Co. of Bay City, Mich., to the design furnished by the Smalley General Co.

Chapter III—Assembly of Five Separate Machines

By E. W. Allardt,

Mechanical Engineer, Babcock and Wilcox Tube Co., Beaver Falls, Pa.

E. W. Allardt

Subject Matter: The machine is unique in that it is constructed from electric arc welded parts and it also produces an electrically welded product. The mill was built to produce standard pipe and tubing in sizes from ½-inch to 3-inches. The mill first forms the strip into a cylindrical tubular shape, then welds the edges together, then shapes the tube and cuts it. Welding is extensively used in coil box, roll stands, sizing mill, gear housing and drive attachments. The factors which led to decisions to build the tube mill completely of arc welded steel were: (a) cost saving which included economy of material and economy of production; (b) time saving; (c) facility of production; (d) durability.

This modern and streamlined assembly of five separate machines, (See Figs. 1 and 2), performs a sequence of operations on flat-coiled strip steel, as follows:

First, it forms the strip into a cylindrical tubular shape, then welds the edges together, then sizes or shapes the tube, then finally cuts the tube into uniform and usuable lengths. The entire assembly should be considered as one machine, or at least as a unit. No one machine can be considered a complete unit in itself.

Such a unit is unique in that it is the first such material-processing assembly to be so completely constructed from electric arc welded parts, and further so in that it produces an electrically welded product.

From a total weight of 64,500 pounds for the entire assembly, 40,750 pounds, or 63 per cent, of this total weight were arc welded parts. The balance of the weight was made up of such items as cast housings, shafts, gears, bearings, adjusting screws and dials, welding transformer and non-ferrous parts for the welder, drive shafts and gearing.

It was only after careful study and design work, and after trial construction and experimenting with similar but separate machines, that this complete unit was constructed. There was no doubt, however, about the substantial savings to be effected by using arc welded type of construction.

Description—The complete electric weld pipe mill shown in illustrations, Figs. 1 and 2, was recently completed and contains interesting features and developments. This mill was built to produce standard pipe and tubing, in sizes from ½-inch to 3-inches inclusive, of low carbon pickled strip steel.

The mill consists of "A" a coil box, "B" forming mill, "C" electric seam welder, "D" sizing and straightening mill and "E" flying cutoff and runout table.

The appearance of the mill is very pleasing with its smooth, flat base sides, its rounded corners and with almost a complete absence of projecting screw heads. Its appearance is one of ruggedness, of durability and of precise con-

struction. Such construction and appearance makes for a desire and ease of continued cleanliness and pride of work.

The coil box "A", Fig. 1, is long enough to hold two large-diameter coils of strip, the first coil paying-off while the second is held in place until the first has been run out. Then the second coil is moved into its paying-off position making space for another coil, which then can be placed in its support while the preceding one is being fed to the forming mill. The side plates are adjustable for different widths of strip as required for the different sizes of tubing.

The coil box is constructed entirely of arc welded steel plate, except for rolls, bearings and screw parts.

Fig. 1. 5-Unit metal forming machine.

The tube forming mill "B", Fig. 1, as well as the sizing and straightening mill "D", Fig. 1, are built up of individual tube-forming roll stands, all assembled on arc welded bases. Each roll stand is complete in itself with tapered, roller bearing mounted, hardened and ground roll shafts, worm gear drive, also running on tapered roller bearings, and toggle gear drive between lower and upper roll shafts. All the gears run in a bath of oil, in dust and oil tight housings. The outboard housings are arranged to slide off the shaft ends after the shaft nut has been removed. Keyways are cut in bottom of housings and when machine is assembled and properly aligned then keys are inserted through keyways, then welded to base top plate. The inner races of the roller bearings in these housings serve also as a spacer to clamp the forming rolls and spacing collars into place.

The roll stands are interchangeable and are connected by couplings that are easily removable.

The upper roll shaft adjusting screws are provided with micrometer indicators to make it possible for the operator to record roll settings for his convenience during a future setup of the same set of tube forming rolls.

The entrance end of the mill is provided with a pair of easily adjusted edging rolls to round objectionable burrs from the slit edges of the strip and to insure that the width of the strip going into the mill and welder is held to decimal tolerances.

In the forming mill the flat strip is progressively formed, while passing

through several pairs of forming rolls, into cylindrical tubular shape with edges finally butting before passing through the welding operation.

In the sizing and straightening mill, the now welded tubing passes through rolls and is reduced in size to the final micrometer dimensions and, by means of adjustable rolls, is finally straightened to commercial tolerances.

The bases for the forming and sizing mills, as well as the edging roll stand, the toggle gear housings and drive attachments are all fabricated of arc welded steel. The design of the bases presented quite a problem to provide a smooth, unbroken exterior surface, and to make provisions for adequate water-tight drains for the soluble oil roll lubricant that must be drained to a sump for recirculation. Several design drawings were made and carefully studied and, when the design was approved, a trial base was constructed and subjected to rigidity tests. The base was found to be rigid and free from structural weaknesses.

To provide a smooth unbroken exterior for this base, the foundation bolting flanges are welded to the inside of outer walls. And because soluble oil must be copiously cascaded over the rolls, while in operation forming the tube, a drain is provided all around the finished top plate in the form of an angle as shown in enlarged section on right hand side of sheet. The soluble oil is drained into the welded-in sump, shown in center of base, from which it is again pumped over the rolls. The top plate is welded to the angle forming the drain and is further supported by partition plates and other stiffeners in a strong and rigid manner. The key shown on the top plate serves to align the drive housings when assembled on the base.

Water-tightness of the drain troughs and interior sump is very necessary for successful, trouble-free and clean operation of this mill. This has not been difficult to obtain because the well-trained welders, having been instructed from "Procedure Handbook of Arc Welding Design and Practice", are thoroughly competent of such construction.

A brief study of the construction of this base will disclose a saving in weight and efficiency of construction, all of which favors arc welded steel instead of a cast base; not only because of the greater strength of steel plate but also because of the facile use of arc welding design and practice.

The toggle gear housing was originally made of a steel casting but, because of machining difficulties due to core sand and warpage, it was finally made of arc welded cold-rolled steel side plates and connecting members, in a jig. This construction allowed the elimination of all machining except the drilling of holes for gear shafts. This reduced the cost to one-third that of a cast part.

The main drive of the mill, not shown in photos, is from a high starting torque motor equipped with a magnetic brake, through a variable speed drive unit having a remote electrical control. This unit is connected to the main drive shaft, that connects the forming and sizing mill, with multiple roller chain adequately protected and running in oil. A jaw clutch is provided in the drive between the mills so either can be run should occasion demand. The various drive brackets and levers are all of arc welded steel.

Next in line is the seam welder "C" in Figs. 1 and 2. In this unit the base and its separate top plate, transformer supports, the cover over all of the rotating parts, roll housings, water cooling connections and various brackets are all made up of plate, or bars, in suitable arc welded assemblies.

Various parts such as auto-transformer, contactor panel and tap switch are mounted in the base. To facilitate assembly, the top plate of the base is separate and bolted to the upper reinforced rim of the base. To the underside

of this top plate is bolted the transformer assembly elevator screw drive and motor, and to the top side is bolted the transformer assembly, welding rolls, outside bead trimmer and other machine parts.

In this machine the rotating copper alloy electrodes contact the opposite sides of the seam to resistively heat the edges to welding temperature. The welding rolls on both sides of the tubing and below the electrodes exert forging pressure to the hot seam and hold it during the almost immediate freezing of the metal. The welder and mill controls, mounted in an arc welded box, are within easy reach of the operator.

Then last in line, "E" in Figs. 1 and 2, is the flying cutoff and its runout table with side discharge, practically all constructed of arc welded steel. The cutoff machine is a recent development and is entirely automatic in its operation. The tube passing through the center core of the arc welded steel cutting head and onto the arc welded steel runout table, strikes a switch, adjustably mounted along the runout table, which causes the carriage holding-latch to be released, allowing the counterweighted carriage assembly to move forward with the tubing. At the instant that the carriage starts its forward movement the gripping chucks, also of welded steel construction, operate to hold the tubing rigidly while at the following instant the cutters move inwardly to make the cut.

The hollow arc welded cutting head rotates on tapered roller bearings in its arc welded steel housing, and together with the enclosed cutter actuating mechanism, is oil bath lubricated.

After the cut has been made the cutters retract, at which instant a switch is operated to cause the solenoid air valve to function the air cylinder which returns the cutter head carriage and chuck assembly to its latched starting position. The cut piece of tubing continues on its way down the live roller table until it strikes a switch, which causes the side discharge arms to deposit the tube onto a truck.

Because the large and long stroke air cylinder requires a considerable volume of air, an air-storage tank is welded into cutoff base and carefully reinforced with welded-in tie rods, and tested to 1500-pound hydrostatic pressure. This tank is shown in Fig. 2 at reducing valve end of base.

In a flying cutoff of this type it is imperative that the weights of all moving parts, particularly those that must be quickly accelerated, be made as light as possible and yet strong enough to stand the severe service. This elimination of weight helps reduce any operating inertia, and provides for considerable increase in operating speeds. Arc welded steel construction meets this condition very satisfactorily and economically.

The counterweight column and its parts shown at end of cutoff, in Fig. 2, are also fabricated of arc welded steel.

Decision Factors—The factors which led to decisions to build this tube mill so completely of arc welded steel were:

(1) Cost saving which includes:
  a. Economy of materials
  b. Economy of production
(2) Time saving
(3) Facility of production
(4) Durability

(1) **Cost Saving**—It was previously mentioned that before this mill was constructed careful study was made, and experimental but similar and separate machines were constructed to prove the efficacy of such construction.

The estimated costs, shown in the following table, can be considered very accurate because of the cost data collected from these similar but separate machines. Actual cost figures, later computed, substantiated these indicated savings.

In the possible cost saving study made, comparison with cast bases indicated a very large saving, as shown in accompanying tables.

Cast Bases	Estimated Weight Lbs.	Casting Cost @ $.065 Lb.	Est. Pattern Time. Hrs.	Pattern Time Cost @ $1.10 Hr.	Lumber Cost @ $110.00 M.Bd.Ft.	Machining Time Hrs. Cost @ $0.90 Hr.	Total
A	1,800	$ 117.00	100	$ 110.00	$ 37.00	10 / 9.00	$ 273.00
B	23,000	1,495.00	350	385.00	200.00	50 / 45.00	2,125.00
C	12,000	780.00	300	330.00	175.00	30 / 27.00	1,312.00
D	6,500	422.50	220	240.00	125.00	20 / 18.00	815.50
E	21,000	1,365.00	500	550.00	280.00	50 / 45.00	2,240.00
Tot.	64,300	4,179.50	1470	1,615.00	817.00	160 / 144.00	6,765.50

Welded Bases	Total Plate Weight - Lbs.	Plate Cost @ $0.04 per Lb.	Cutting Gas Ft. Cost	Total Time Hrs. Layout 10%; Cutting 15%; Setup 25%; Welding 50%	Total Welding Shop Cost @ $1.15 Per Hr. Ave.	Welding Rod Weight Cost @ $.075 Lb.	K.W. Welding Cur. @ 1½¢ per K.W. 16 K.W.H. 1/4" & 5/16" Rods	Machining Time. Cost @ $0.90 Hr.	Total
A	900	$ 36.00	20 / .02	29	33.40	20 / 1.50	240 / 3.60	10 / 9.00	$ 83.52
B	11,000	440.00	200 / .15	85	98.00	220 / 16.50	680 / 10.20	60 / 54.00	618.85
C	7,000	280.00	130 / .10	75	86.50	150 / 11.50	600 / 9.00	35 / 31.50	418.60
D	3,100	124.00	65 / .05	70	80.60	60 / 4.50	560 / 8.40	25 / 22.50	239.05
E	10,500	420.00	200 / .15	136	157.00	230 / 17.30	1080 / 16.40	60 / 54.00	664.85
Tot.	32,500	1,300.00	.47	395	455.50	51.30	47.60	190 / 190.00	2,024.87

Recapitulation—From the foregoing tables, the following significant figures are obtained:

Total time for cast bases.. 1,630 hours
Total time for arc welded bases............................ 585 hours

Total time Saved.. 1,045 hours

Total weight cast bases..64,300 pounds

Total weight arc welded bases............................32,500 pounds

Total weight Saved.....................................31,800 pounds
Total casting costs including machining..$6,765.50

But deducting for continued pattern use by assuming that three castings can be made from patterns before total damage to patterns and coreboxes requires additional pattern time equivalent to the original time, then only one-third of pattern building cost should be charged to first job. This amount is $811 instead of $2,432 which included time and lumber, a deductible difference of:.............$1,621.00

which makes—

Net cast base cost..$5,144.50
Total arc welded base cost.. 2,024.87

Total savings $3,119.63

Percentage time Saved = ... 64%
Percentage weight saved = ... 49.5%
Percentage Cost saved = ... 61%

The results of this analysis show a total time saving of 1,045 hours, which represents a great saving and means economy of production. The material saving of 31,800 pounds in bases alone represents economy of materials, which in such critical times as the present, means conservation at its best. The cost saving of $3,119.63, in bases for this one mill alone, does not represent the total cost saving of all contingent items as shipping cost, handling etc., nor does it represent the total saved on the entire mill because many more parts on this mill were made of arc welded construction.

It is interesting to note that the total casting cost including machining, as estimated $\frac{\$5,144.50}{64,300 \text{ lbs.}} = \$0.08$ per pound, while the total estimated cost for arc welded bases, also including machining, is $\frac{\$2,024.87}{32,500 \text{ lbs.}} = \$0.0625$ per pound.

Estimated Total Annual Gross Cost Saving—If the above total of cost saved for bases alone for this one mill is multipled by seven, which is the number of electric weld mills built of this construction in the past year, a total saving of $21,837.40 is obtained.

The total saving of time for this number of mills, 7,315 hours, represents an appreciated economy of time released for other vital production.

Fig. 2. Another view of 5-unit metal forming machine.

If all other arc welded parts used in this mill are considered, the total saving would be approximately $25,000 and 8,000 hours time.

If all other manufacturers making similar mills would use arc welded construction as above described, the total saving would be approximately $100,000 and 32,000 hours time. When this saving is considered during peace times, the effect is gratifying and demands the use of arc welding, but even more acutely during these times of stress and extreme urgency.

The factory cost difference between cast bases and welded bases, while astonishing in its amount, was not unexpected, because of previous experiences. Because of the difference in weights, while retaining similar strength of structure, economy of material is enjoyed as well as economy in final shipping costs. And especially, during these times of optimum effort for conservation of materials to effect a greater spread of militarily useful goods, is this weight and material saving beneficial.

(2) **Time Saving**—The indicated saving of time, 1045 hours, between the two sorts of bases is, in general, indicative of the saving to be enjoyed using arc welded structures and parts. Particularly is this so if one considers the time saved by not having to wait for delivery of castings such as here described, in addition to the direct saving of time between actual pattern making time and welding time on similar parts.

The desire on the part of workmen to continue and to demand such time saving seems to become inherent in organizations using arc welded parts and equipment. Workmen become impatient, if once they become accustomed to this time economy, when delays are caused by failure to receive cast parts when needed.

(3) **Facility of Production**—The facility of arc welded construction is so apparent that it hardly seems necessary to mention it. Some of the foregoing remarks apply to the facility but probably one other comes to mind. During the construction of a mill as herein described, minor changes, due to errors, may become necessary. These errors are easily corrected with dispatch and usually without the time necessary to disassemble, as might be the case with cast structures. And furthermore, improvements thought of during construction and assembly, can and are made without the necessity of pattern changes and new castings, simply by fabrication done quickly on the job. The importance and value of such facility are quickly accepted by all workmen concerned and seem to engender suggestions for improvements and help to speed up the final construction, instead of hindering it.

(4) **Durability**—The durability of such arc welded equipment is beyond dispute. In older types of similar construction it was not uncommon to have a customer report parts, bases, legs, brackets, covers and other parts broken in transit or during operation of equipment. Since the adoption of arc welded construction, such complaints have entirely disappeared.

It is necessary in mills of this sort that there be no warpage or deflection that would cause rolls and other accessory parts to become misaligned. These mills are entirely free from such trouble. Some of these bases have lubricant reservoirs welded in, others have soluble oil sumps or tanks welded in as part of the structure, others have air tanks, adequately re-enforced, built in as a necessity for the successful operation. In all of such instances no trouble or leakage has been encountered even though such parts have been subjected to long hauls and shipment.

Many of the bases above mentioned are not normalized, but have peened welds for the purpose of counteracting the natural deflections from heat of welds. Housings of welded steel where alignment of roller bearing mounted shafts and parts are included are usually normalized to insure stability of the structure.

Possible Future Construction—Recently, several roller head drive housings rather intricate in design and shape, complete with cover and caps, were made of arc welded steel for a similar mill because some castings could not be obtained in time for scheduled completion. In another instance, such arc welded housings were quickly made to replace broken cast housings, not only because castings could not be obtained in time to get customer back into production quickly, but to furnish stronger parts. And as a result of this recent expedient necessity, results indicate that with better facilities for duplicative manufacture of component sections, arc welded housings as here used could be competitive with these rather intricate castings.

Conclusion—Only one conclusion is possible It is imperative that a greater use be made of arc welded machine parts and structures.

The undeniable economies of materials incident to manufacture and construction, the great savings in man hours; man hours vitally necessary to our production efforts, the facility of production, the utility and durability of the finished product; all these are now our goal.

And under the tempo of present conditions, where there is a sense of urgency, of purposefulness, of intense effort and determination to get things finished ahead of schedule, all of these vitally important elements are swiftly advanced and realized, whenever and wherever arc welded construction is advocated and applied.

Chapter IV—Machine for Production of Domed Silo Roofs

By WALTER RUTTEN,

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Walter Rutten

Subject Matter: Silo roofs built of plates with slip joints This eliminates to a large extent bolted joints, roof sheet sections are shaped to resemble "orange-peels" The machine consists of forming heads on a swivel base so that the heads will move back and forth, swing to right and left and follow any desired radius. Extensive use is made of guide bars, rolls and tacks Sheets come out of main machine cut to shape but flat, are then given desired curvature, ribs and interlocking joints Over a period of 18 months, more than 110,000 sheets were formed for over 3,700 roofs Arc welding used for joining bars, flats and parts

The entering of this subject matter in the James F Lincoln Arc Welding Foundation Progress Program, clearly illustrates how an idea has been developed into a practical and profitable machine "via the arc welding route"

To start out describing this subject, I wish to make it clear that I am no engineer, no trained mechanic, no draftsman and no high school graduate, therefore, my explanations and descriptions will be in plain everyday language

I am 31 years old, raised on a farm, worked in a silo factory, making and building silos for eight years During 1937, my father and I designed and worked out a metal dome silo roof This was something new and

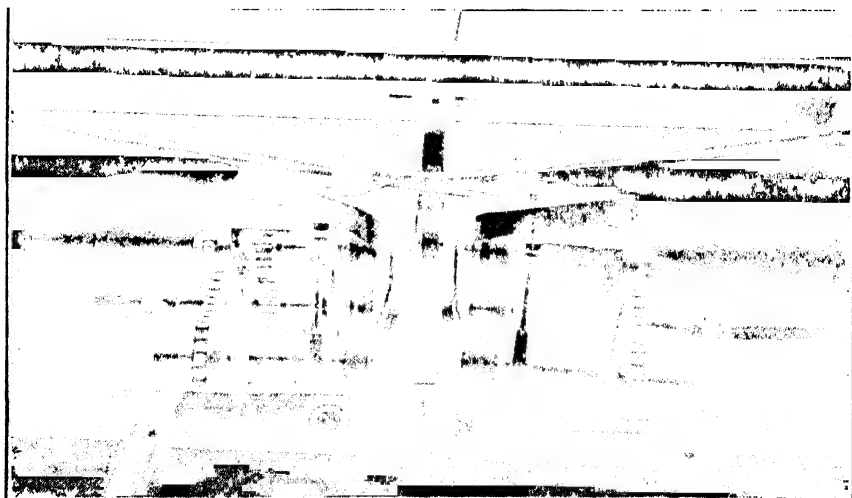



Fig. 1. Close-up of machine.

different from any silo roof ever before made, therefore, special equipment was required all of which we designed and had made to order. Finally, we started manufacturing metal dome silo roofs on a commercial scale. After considerable experience with this type, we discovered where substantial improvements could be made which is only natural from most any new item. During 1939 we conceived the idea of a slip-joint dome roof by which we could eliminate nearly all the bolts heretofore used as also greatly reduce the overall production cost.

Our next problem was to get equipment with which to make and form this new slip-joint type roof. The machine finally designed and made, (See Fig. 1), is the subject matter of this writing.

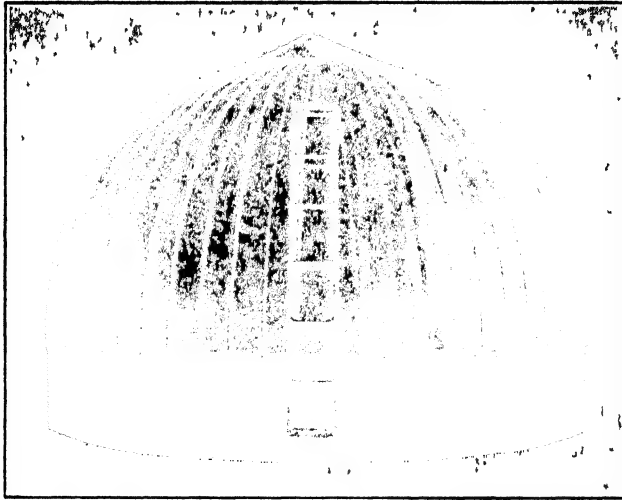



Fig. 2. The dome silo roof.

This new or improved dome roof is shown in Fig. 2. In Fig. 3 are shown a cross-section of a formed roof sheet, (at top), two roof sheet sections assembled, (at center), and a drive lug (finishing lug) set in the joint between two roof sheets, (at bottom). After the roof has been erected and properly adjusted, those drive lugs are placed and driven in the joints between all sheets which ties all sheets rigid.

It will be understood that the sheets for a dome roof must be cut and formed on a radius, sometimes called, "orange-peel" shape, (See Fig. 4).

Forming sheets on a radius is entirely different and requires different equipment from that of forming straight sheets. I made up small samples formed by hand to show the forming required, presented such samples to those I enquired of to get a machine made. One representative from a company which does a lot of metal forming and which maintains an engineering and machine designing department, took some samples along. Their engineers gave the matter their careful consideration and finally decided that it could not be done. They in turn passed the samples on to one of the largest roll forming machine manufacturers in the United States.

Their engineers, after going over the proposition also concluded that it could not be done. Others we contacted gave us the same replies, namely, that light metal cannot be formed against itself on a radius.

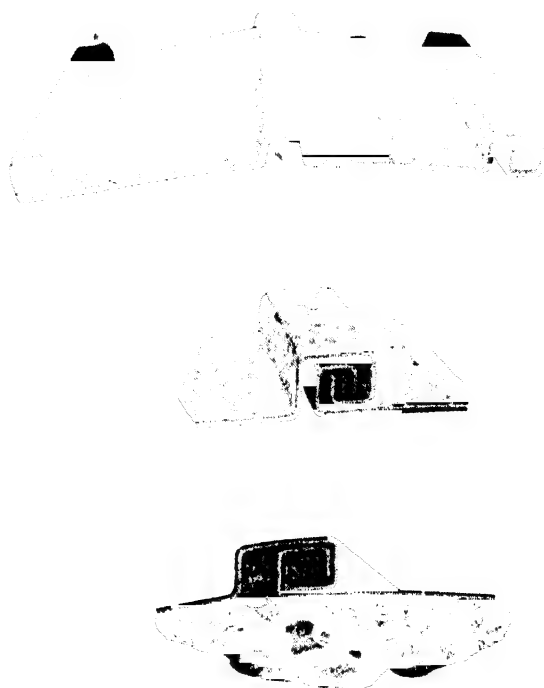



Fig. 3. Cross section of formed roof sheet, (top), 2 roof sheet sections assembled, (center), and drive lug sheet in joint between 2 roof sheets, (bottom).

For a while I gave the matter a lot of thought and study and formed several imaginary models and designs in my mind and finally decided to try to make a machine myself. I told my father that if he would consent to buying the parts needed, including a lathe and an arc welder, I would make a machine myself.

Father replied to me saying, "Son, you are too young and inexperienced to tackle anything like that which many trained engineers say is impossible."

My reply was, "Dad, the idea of this new roof looks so good, it has to be worked out some way."

Dad said, "O. K. if you are so determined, go ahead. It will, at least, give you a lot of valuable experience!"

I made up a list and ordered a lot of parts, gears, sprockets, drive chain, rounds, squares, flats, channels, angles, etc., including a lathe and arc welder. First to arrive were the lathe and arc welder, neither of which I ever operated before. I started practicing on those mostly after working hours, took a few welding lessons, read up on operating a lathe and after considerable practice on odd pieces, I felt capable of trying on the machine.

For a little over a year, I spent most of my idle time, evenings and some Sundays, thinking, studying and working on the machine. The work, although tedious at times, was always interesting and very educational. In June of 1940, the machine was ready and working.

I will now explain to the best of my ability how the various parts were

made and why I was so determined that a machine could be made to do this special forming. All forming machines on which we could find literature showed the forming heads rigidly mounted in a straight line. On those types of machines it would be impossible to form metal on a radius.

I conceived the idea of mounting the forming heads in a floating position on a swivel base so that the heads would move back and forth, also swing to right or left following any desired radius. This was done by guiding the heads by means of templets in the form of tracks (which will be called tracks hereafter). The tracks being shaped to the exact radius and spaced to the exact width allow forming the resultant or finished sheets, (See Fig. 5), No.'s 72 and 74, (at top), also 73 and 75, (at bottom).

The tracks are mounted on a movable feed table slightly raised above the table. The feed table while traveling forward goes under the heads while the tracks being slightly raised pass through head-guiding rolls which

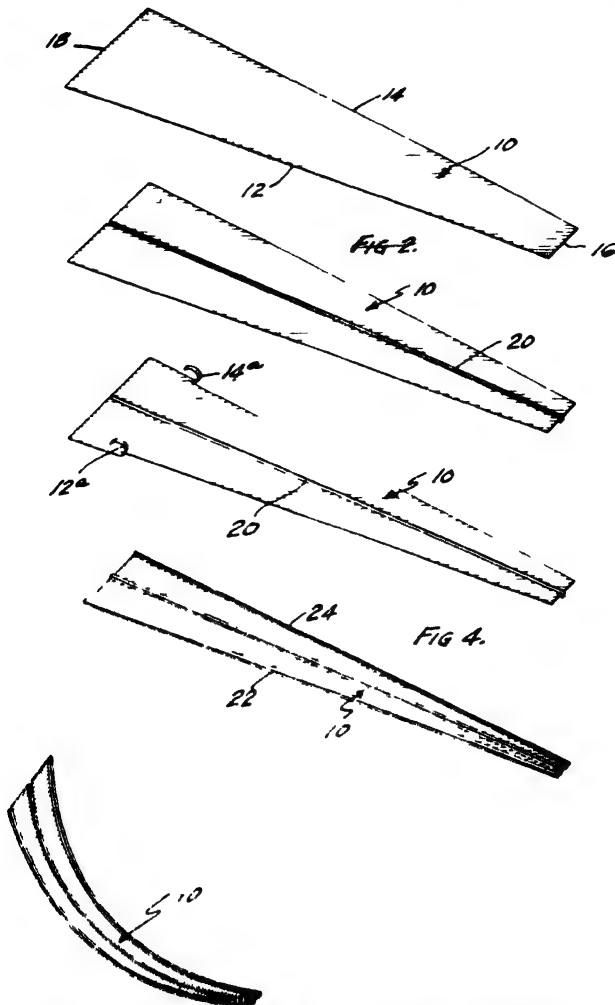



Fig. 4. Sheets for dome roof formed on a radius to "orange-peel" shape.

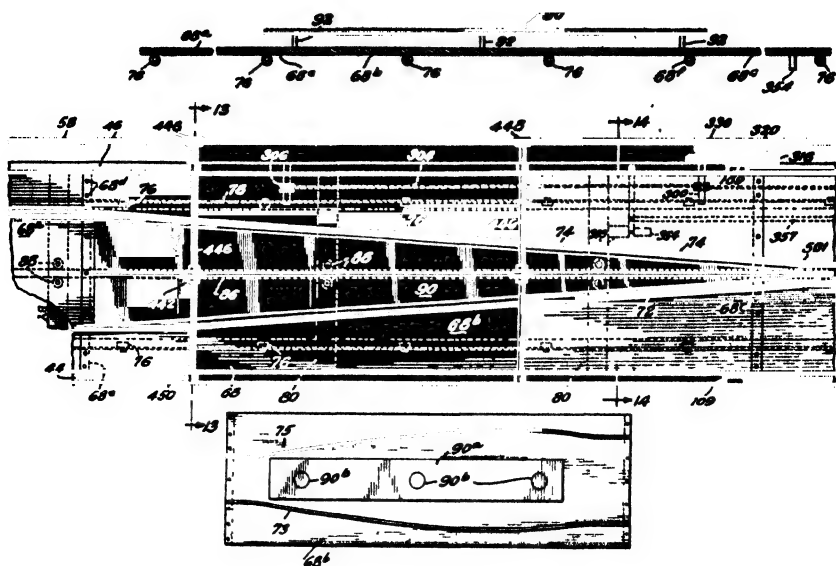



Fig. 5. Tracks mounted on movable feed table.

are mounted on the base of the heads, (See No. 138, Fig. 6). The heads are mounted on a swivel base, held in a swiveling position by a bolt shown as No. 123a in Fig. 6. The heads, while moving forward and back, are held in alignment by a guiding bar No. 122, Fig. 6, which guides from the base, other overhead guiding bars are shown at No.'s 102 and 148 in Fig. 7.

As the feeding table travels forward, the tracks being attached thereto, likewise travel forward. In doing so, all forming heads move back or forward or turn on their base according to the width, shape or radius of the tracks, thus, trimming and forming the sheets to that same width, shape or radius. One set of tracks is required for each different size roof, each set having the proper spacing and radius for its size roof. To change from making one size roof to another, we simply change tracks.

A section of straight tracks is mounted stationary on the forepart of the table, (No. 96, Fig. 8). This straight portion of track always brings all forming heads back in straight starting position when feeding table is returned to starting point.

All sheets are previously blanked to proper size diagonally, (See top, Fig. 4). Those sheets are fed into the first set of forming rolls, (See No. 10, Fig. 9), where the first or center rib is formed on the sheets. Those first forming rolls deposit the sheets on an island-like table, (No. 90, Fig. 5, top), where the sheet is held in position and fed on into the main forming rolls by feed rolls, (No. 442, center in Fig. 5).

The island is a second table built on top and slightly higher on main feeding table. The purpose is to raise the sheet up and in direct line with the center of the forming rolls, (No. 90 in Fig. 5).

As the table moves forward the sheet feeds into the trimming and forming rolls. The first forming heads on each side are equipped with slitting knives. As the sheet moves forward with the table and tracks, the tracks move the slitting and forming heads outward in conformity with the width

and radius of the tracks, thus trimming and forming the sheet to the exact width and radius of the tracks.

All heads are so mounted and lined up with the tracks that they are always all in proper alignment to trim and form without undue friction. The completely formed sheet comes out of the main machine flat and from here the sheet passes on into and through the final curving heads and rolls shown in Fig. 10; also in photo, Fig. 1. Those curving rolls are adjustable so as to form to any desired curvature and are mounted in a floating position, guided in or out by the two outside seams of the sheet passing through. After a sheet has passed through, springs draw the heads back into starting position.

The blank sheets as shown in Fig. 4, make one pass through the machine and come out completely trimmed, formed and curved to any predetermined size, width, radius and curvature.

The machine has a normal capacity of six sheets per minute, or one complete average size roof in six minutes. Sheets for over 3700 roofs were formed on this machine in 18 months, or a total of over 110,000 sheets.

Shortly after the machine was in operation, every one of the firms who formerly said it could not be done, sent one and in some cases, two of their engineers to see the machine in operation. All commented on the fine forming job being done, all admitted that the floating forming heads guided by moving tracks were the secret of the machine.

Now regarding the cost and saving in making this machine by arc welding instead of the usual pattern method, I can say that one company's representative said, after inspecting the machine and seeing it in operation, "If we were to make a machine like it, we would demand a $10,000 cash-in-advance payment before we would even start."

The complication or scope of the machine is clearly evidenced in the description and illustration herewith, and the fact that the patent attorneys used 62 pages of descriptive matter in the patent application.

Fig. 8. Details of forming heads.

Fig. 7. Heads are held in alignment by guiding bars.

Fig. 8. Section of straight tracks.

During the process of making the machine and trying it step by step, several changes had to be made, mostly in the form of offsets and extension arms on the heads for mounting special forming rolls and plows, (booster rolls and guides) all of which, by the use of the arc welder, was done comparatively easily, inexpensively and conveniently because in case an offset or arm happened to be set at a wrong angle, it was easily removed and rewelded in a few minutes' time, while if all that had to been done by patterns and castings, the cost of the patterns and castings alone would have been prohibitive especially on a more or less experimental job.

It may be well for comparison to mention a few of the welded items to show the simplicity in making up some of the parts in question by the arc welding method as against patterns and castings. For instance, in making the drive sleeves to fit over a square drive shaft, I took four pieces of cold rolled flats, clamped them on a piece of square bar, welded the corners along the sides, then turned them around on the lathe. The result was strong, uniform, perfect-fitting sleeves.

The forming heads, for instance, had to be compact and strong. I clamped pieces of cold rolled flats together, and welded the sides and ground them smooth. The result was compact, uniform strong heads with a minimum amount of work, a little grinding but no milling, no patterns nor castings. Similar methods were followed with the universal joints. In fact, the entire machine from start to finish was made by welding the various parts together.

While I cannot give an accurate cost figure, I do know that the saving by making the machine via the arc welding route as against the pattern and casting method was a good large amount.

In addition to the saving in making the machine, there is also a very substantial saving in production cost in the product made on the machine

Fig. 9. Sheet passing into first set of forming rolls.

Fig. 10. Sheet passing through the final curving heads and rolls.

Fig. 11. Six forming rolls mounted on single heading.

as will be noted by the following figures. These figures are based on a 14-foot size roof which is a fair average size, and represents the saving between the cost of the roofs we formerly made and the new slip-joint roofs made on this new machine.

Saving in galvanized sheets 90 lbs. at .04¢ per lb.	$ 3.60
Manufacturing labor 5 man hours at .60¢	3.00
Crating lumber 60 ft. at $35.00 per M ft.	2.10
300 bolts at 50¢ per 100	1.50
Outgoing freight on 110 lbs. (difference in weight) at an average rate of .70¢ per 100 lbs.	.77
Erecting labor 12 man hours at .40¢ per hour	4.80
	$15.77

This makes a total saving on each roof of $15 77, or on 3700 roofs, a saving of $58,349 most of which has been passed on to customers in reduced selling prices Then, too, the result is an absolutely water-tight roof of great structural strength, very attractive in appearance with increased filling or storage capacity, all of which was made possible through use of the arc welder

Fig. 12. From main forming rolls sheet passes into final curving rolls.

Fig. 13. The curving rolls, (top), and the drive hook-up, drive shafts, sprockets, drive chains, etc., (center and bottom).

Here follows to the best of my ability the procedures taken in the making of the machine. Realizing from the start that many forming heads and rolls were required, I laid out a frame 42 feet long overall, and designed and mounted the forming heads in pairs, each pair on a swivel base plate. One head of each pair is connected to a drive shaft, the pair being geared together with a drive chain, each pair of forming heads thus working as a unit, (See Figs. 6 and 8). Fig. 6 shows a top cross section view of a pair of forming heads.

The universal joints were all made by welding the various pieces together.

All drive sleeves to fit over square shafts were likewise made by welding several pieces together.

The forming heads are all made by welding several pieces of steel plates and flats together. The several pieces were set together and welded into heads. It was necessary to weld several extensions and offsets for mounting special rolls, guides and plows at various angles and positions, (See Fig. 11), where six forming rolls are shown mounted on one single head.

In proceeding to make the machine, I mounted the first two pairs of heads, one on each side, made the slitting knives and first-forming rolls and tried this first operation, changing the rolls until they functioned properly. I then proceeded with the next two pairs of heads in like manner and so on, one pair after the other, always trying those previously mounted.

As the sheet passed through the first three sets of rolls and was taking on shape, the succeeding rolls became more difficult. In several instances, rolls had to be rebuilt, welded up and turned to different size and shape, also adding special rolls, shoes and plows at different angles.

I will now describe briefly the general operation of the various parts by again referring to figures, and photos.

Fig. 14. End view of island on feeding table, (top), and side table return lever, (bottom).

Fig. 4, (top), shows sheet cut diagonally ready to go into the machine. The sheets are fed narrow end first into the machine at top, Fig. 9. These first rolls form the center rib on the sheet, (See second from top, Fig. 4). As the sheet passes through these first rolls, it is deposited on an island-like table, (See top, Fig. 5), where the hold-down and feeding rolls (No. 442) feed the sheet on into the main forming machine heads, where the sheet passes through 22 forming heads, (See No. 98, Fig. 8).

From the main forming rolls, the sheet passes on into the final curving rolls, (See top, Fig. 12, also top, Fig. 13). These rolls are adjustable so as to curve the sheets to any desired curvature.

An end view of the island on the feeding table is shown at top, Fig. 14 with a sheet, No. 10, placed in position under the hold-down and feeding roll No. 442. The island is sufficiently raised above the main table so that the sheet is in direct alignment with center of the slitting and forming rolls.

Feed table return lever is shown at No. 346, bottom, Fig. 14. The clutch for same is shown at No. 300.

The motor power mounting is shown at bottom, Fig. 15.

Fig. 13, center and bottom, shows the driving hook-up, drive shafts, sprockets, drive chains, etc. Fig. 13, top, shows a side view of the main frame.

The machine as herein described and illustrated refers to the cutting and forming of dome roof sectors. However, the machine is not limited to that one particular job. It is adaptable to many other uses such as cutting, sawing and/or forming different materials in or to a wide variety of different shapes and sizes as for instance, covering sectors for dirigibles, airplanes or the like, or the forming of tubing, straight or tapered. It can likewise saw or permit mounting other cutting tools for sawing, cutting or slitting leather, paper, wall board, lumber or the like, also cutting or sawing them to most any reasonable size or shape. A heavier-built machine could be used for cutting plates for ball-shaped tanks or the like.

Chapter V—Speedy Connector for Welding Cable

By W. G. Donaldson,
Foreman of Electrical Department, Standard Oil Co. of Indiana, Sugar Creek, Missouri

W. G. Donaldson

Subject Matter: Connector requires clean, tight, metal-to-metal, surface contact which is free from oxide. Copper oxide is hard to clean off, especially if it is an accumulation of some time. A cable connector design which uses flat contact surfaces facilitates easy cleaning. It is stated that it should be cleaned and the tightness adjusted every month. Over 100 of these connectors have been put in service without troubles. They are of arc welded construction and the simple design indicates low cost.

I would like to start by telling why I designed and constructed such a connector as I am describing. I am sure it will help me set out certain points clearer as I had reason for designing such a connector and knew exactly what improvements, over other such connectors I wanted before I decided how such a connector could be constructed.

For more than twenty years I have been servicing electric welding machines. From the first they interested me a little more than any other type of electrical equipment which was my job to keep in condition. The neat way two pieces of metal could be put together fascinated me, enough so that I learned to weld and was interested in the strength of the weld. I soon learned that two welds looking very much the same could be "poles apart", one good, the other bad. It came to my observation many times, that a man whom I knew to be an excellent welder, (one who knew how to set his machine, knew his metal and was good at holding the arc) would sometimes make a bad weld on an important job where I knew he had tried his best to make a good one.

In such cases, the welding machine seemed to be working perfectly, but on inquiring of the welder as to how the machine had acted, I invariably got an answer something like this, "Well, pretty good, but I didn't seem to be able to get her set just right."

I did a lot of experimenting, but to cut this short, I learned that one little thing neglected, can cause a welding machine, otherwise in A-1 condition, to spoil an important job.

Concentrating on this caused me to watch every case of trouble closely. I found that on welding machines which were well cared for, most all such trouble came from a thing so simple it was overlooked. It was this. All connections are supposed to be metal to metal. Where not soldered, the metals were cleaned and bolted tightly together, then passed as OK. No doubt they were good connections then, but unless the connection was tinned and sweated or sealed, copper oxide or copper sulphide will spoil it sooner or later according to surrounding atmospheric conditions. Copper sulphide is not so bad because it shows up in a way which attracts attention and is cleaned, but copper oxide

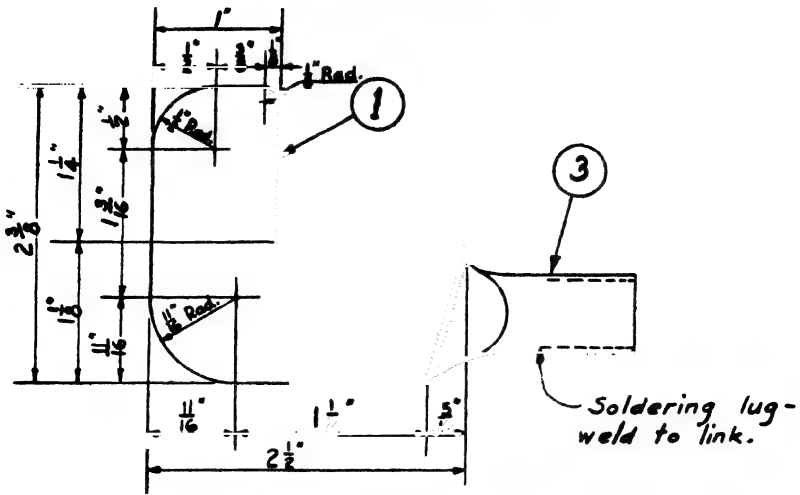
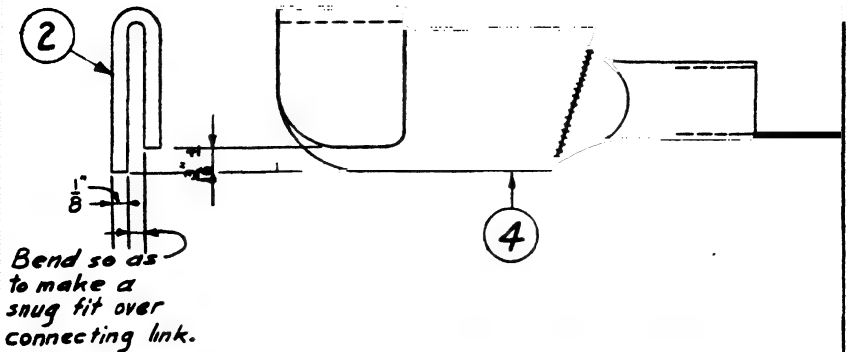



Fig. 1. Development and detail of connecting link.

does not attract attention and on inspection an oxidized joint is apt to be felt for tightness and passed.

My experience along this line convinced me it was nothing short of foolishness to allow so small a thing the chance to weaken an important job. Every connection on every welding machine should be tinned and sweated or cleaned regularly. This was a small item in maintenance until it came to the cable connections. Here all sorts of connectors are used. Terminal lugs bolted together plus all kinds of portable or quick connectors. All of these were a problem. All manufacturers of quick connectors seemed to go on the theory that their connectors were self cleaning. This might be so

provided the connectors were taken apart and put together at regular short intervals, which is seldom if ever the case.

Sometimes these connectors are in service at one place for long intervals or apart and out of service for some time. At such times a coating of copper oxide will build up and give a piece of emery-cloth quite a tussle. After a time the oxide coating gets so heavy that the connector is hard to put together. When it gets this bad a welder will seldom go to the trouble to clean it and put it all the way together. Instead he will stab it part way together and let it go at that. Most of these connectors if put all the way together can be turned and locked. When they are not put all the way together the locking device is out, if, for instance, a connector is only part way together, not locked, and at the same time in service pulling around 250 amperes. If, at such time, someone happens to stumble on the cable and pull the connector apart under load, the arc drawn will likely call for a connector repair which will render the whole welding unit useless for a time.

A natural thought is: why can't these connectors be cleaned? Practically all of them are of the cylindrical male and female type one way or another, with contours and recesses which are almost impossible to clean. If one takes enough time to clean one of them thoroughly he is soon apt to find that he has a loose connector.

Another thing against them is they cost too much. Every cable connection between the welding machine and the electrode holder should be a quick connector. They speed up the work and make a stock of welding cable more flexible. It isn't hard to show anyone that they will more than pay for themselves in time saved. Most anyone will agree that it would pay to have all cable connectors the quick type, but try to sell him one for every place. Generally, he will buy only a small part of what he agrees he should have. The outlay in dollars and cents is too great.

Knowing all I have said to be true, many years back I started wondering if a more serviceable connector couldn't be made. Some of them on the market were so perfectly made and pretty to look at (and cost enough to be that way) that it looked like all the best ideas had been used up. But they all had the same faults and I never was able to get it completely off my mind. As I said before I knew what I wanted in the way of improvements. I wanted a connector which could be cleaned perfectly in a "jiffy". One in which the metal lost by cleaning could be compensated for by a reset. I knew you couldn't keep the oxides from forming on open metal and that the only way to beat them was to have it so they could be cleaned off easily. I knew that to have such a connector all contacts would have to be flat as any curvatures would be hard to clean, especially on the inner walls. I wanted an either end job so you couldn't get your cable laid out, wrong end to. And I wanted a connector which could be made at small cost, so that anyone needing cable connectors wouldn't be scared off by the price.

It was years before my mind happened to "click" along the right line but one-day back in the middle of 1940 an idea came to me. I stopped right where I was, cut out two pieces of paper exactly alike with my pocketknife, folded each piece of paper the same way and put them together. I felt certain I had found the connecting construction I had been looking for. The farther I went with it the better it looked to me and it is this type connecting construction plus another piece and an electric weld which helped me out.

The nearest I had to the metal I wanted for constructing this connector was 14-gauge flat copper. I made my connecting links from this metal. After I had the connecting links made, a way of attaching them to the welding

cable was my problem. The way I finally found to do this was to electric weld a center-drawn soldering lug to the end of each of the flat connecting links. To do this welding job I used phosphor bronze shielded arc electrodes. Our welders had some trouble with this rod as it was new to all of them but now they handle it OK.

The first connector I made of this type didn't look like much. We spoiled several until the welder got the knack of setting his machine, holding proper arc, etc. The first good one we got probably cost (as near as I can recall) between seven and ten dollars in time and material.

I am rigged up at present to make this connector, metal parts only, at a cost of not over 66-cents, as follows:

2-center drawn soldering lugs.......not over	.31
1pc—4¾" X 2½" X 14 gauge flat copper.......	.07
Tin Shop time.......	.13
Welding Shop time.......	.15
Total cost....	$.66

I have given the quantity production considerable thought. While I may be off a little in my calculations, I will be on the long and not the short side.

The machine equipment needed which would consist of: 1-Punch-press, with fuller and cut-off attachments; 1-Folding machine; 1-Small Elec. Emery and Wire, Grinding and Buffing wheels; 1-Gap Gauge Set, made similar to Blacksmith's Vise which is foot operated; 1-Holding Jig; 1-300-ampere arc welder.

Also a stock of material as follows:

A quantity of flat metal, proper gauge, proper consistency. A quantity of copper pipe ⅝-inch outside diameter × ½-inch inside diameter.

Now take Fig. 1. The drawings are actual size except in thickness. The thickness shown on drawing is what I figure to use later on for reason given later in this paper.

At Number 1 of Fig. 1 is shown the exact size and shape of a piece of flat metal. Two strokes of a punch-press makes two such pieces and the time consumed will not be over 10-seconds. Now take these two pieces and turn to the wire buffing wheel. Buff all edge corners slightly rounding. Time consumed is not over 20-seconds. Now take these two pieces to the folding machine. Insert smaller end of the square-like pieces one at a time in the holding slot of the folding machine and operate machine twice. This operation makes the pieces as shown at Numbers 2 and 4 of Fig. 1. It does a perfect job and the time spent on both pieces will not exceed 15-seconds. Now take these two pieces to the foot-operated set. Slip the gap, shown at Number 2 of Fig. 1, over the tongue-like gauge in center of jaws of set and step on actuating lever. This make the setting perfect as the backspring of the metal is allowed for, and the time spent in this operation will not be over 10-seconds. You now have one pair of connecting links complete.

Now take a piece of copper pipe and cut off a piece 3-inches long. Place one end of the 3-inch piece of pipe in the holding gauge to one side of the fuller tool of the punch-press. (This holding gauge holds the piece of pipe on center between fuller jaws). Operate punch-press. This makes two center drawn soldering lugs in one piece. Now place one end of the 3-inch piece in the holding gauge to one side of the cutting tool of punch-press. (This holding gauge holds the flat made by the fuller tool at proper angle and on center

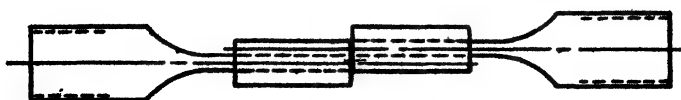
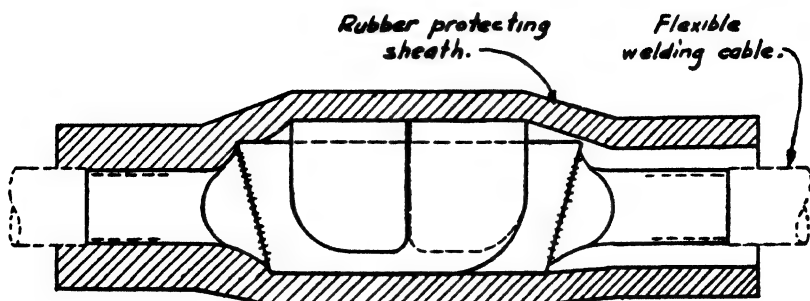



Fig. 2. Top and side views of connecting link.

between cutting jaws). Now operate punch-press. The cutting jaws barely miss coming together which keeps them from damaging each other. Although the 3-inch piece will not be cut cleanly in half it can be broken in halves easily with the hands. The cut on each side is V-shaped which leaves a beveled edge on both sides ideal for welding. The operations for making these two soldering lugs complete will not take over $1\frac{1}{2}$-minutes.

Now take one soldering lug and one connecting link and place them in a holding device made to hold both pieces separately in the position shown at Number 4 on Fig. 1. With the electric welding machine, run a bead along the dotted angle, using the shielded bronze electrode. Turn the piece over and run the same kind of bead along the angle on the other side. Now take it to the emery and buffing wheels for smoothing up the beads. Now take the other soldering lug and the other connecting link and do the same to them. This welding and buffing operation should not take over $3\frac{1}{2}$-minutes, which makes a total of about 6-minutes of time spent on one connector.

6-minutes time @ $1.50 per hour	$ .15
Material will cost—not over	.14
	$ .29

At this time I would like to explain the insulating sleeve used with this connector and its cost.

Up to now I have made this sleeve with two pieces of rubber hose, in the

following manner. I took one piece of hose 1½-inches outside diameter x 1-inch inside diameter x 6⅛-inches long, another piece 1-inch outside diameter x ⅝-inch inside diameter x 2$\frac{1}{16}$-inches long. With rubber cement, I cemented the 2$\frac{1}{16}$-inch piece inside the 6⅛-inch piece, leaving them flush at one end, (See Number 6 on Fig. 2). The inner piece of hose allows the insulating sleeve to go only so far up on the connector and it cannot lose off when the connector is apart. It insulates as well as locks the connector in working position. The print only shows one sleeve but there are two at each connector, one at each end of each cable length. When the connector is in working position only one sleeve is used, but when it is apart and out of service an insulating sleeve is pulled down over each half of the connector to protect it in transit. More cable connectors are damaged when apart, being moved around, than when together and working. The cost of each insulating sleeve is a fraction less than $0.25 making the cost of them to each connector amount to $0.50. Later I figure to have these molded from synthetic rubber already commonly in use in gasoline filling station hoses. This material will do the job better all the way round as it withstands oils better and is slightly stiffer. I have reason to believe it will cost less than pure rubber but cannot say exactly what the cost will be.

The way I construct this connector at present it costs $.50 for the insulating sleeves and $.66 for the metal parts, or a total of $1.16.

Its closest competitor sells for $2.80 each, a difference of $1 64 each. We have at least 150 of my type in service in the plant now and have not used any other kind for several months. Using these figures we have saved $246 on purchase price. But that isn't the case because we wouldn't have bought that many of the other type. The real saving comes with the fact that we now have a quick connector in every place and the time they save amounts to far more than the difference in price of connectors. The purchase price however is very important as it will have a lot to do with the number of quick connectors used. I feel certain that my connector can be made on quantity production for considerable less than I have tried to picture. I know it will last longer and give better service than any other type which I have ever seen.

I haven't any way of knowing how many such connectors are used over the country but I'm sure in my own mind that if I can get this connector perfected and on quantity production there will be more such connectors used than were ever used before.

Of the 150 connectors we have in service I have not had one trouble call on any of them and I know how that compares with what we used to have on the other types.

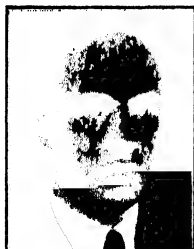
I aim to have them cleaned and reset every month. This service takes about two minutes to each connector and leaves it perfectly clean and perfectly reset. This service cannot be rendered to any of the other types. I have constructed a double flat spring arrangement which takes a piece of emery cloth for cleaning the gap and shank. A set made in parallel plier fashion, with a tongue which is the gap gauge, resets the gap with one squeeze of the handles.

Although the ones we have in service are performing better than any we have ever used, still for the sake of ruggedness I figure to make the connecting links two gauges heavier and add enough zinc to the copper to bring the proper stiffness.

I have applied for a patent on this connector, on my own. I first gave it to the company for which I work but it being out of their line from a manufacturing standpoint, they released it back to me at my request.

Chapter VI—Large Water Turbine Installations

By HERBERT STONE,

Assistant Works Manager, Markham and Co. Ltd., Chesterfield, England

Herbert Stone

Subject Matter: Two water turbines of 30,000 horsepower each, were made in 1936 in which the principal non-moving parts were of either cast steel or riveted steel plate construction. Two additional units were built in 1942 which were identical with the others, except that all the large steel castings and all the riveted work have been abolished in favor of welded methods. The saving in cost was 16 per cent. The saving in weight was 20 per cent or 12-tons of steel for each of the turbines described. An important advantage of welding was the marked saving in time of manufacture. It is expected that the smoother surfaces will give higher efficiency of the turbine.

This paper concerns the progress made in the application of arc welding to the design and manufacture of large water turbine installations used for the generation of electric power. In it the writer is able to compare the methods used in the construction of two examples. The first of these being two turbines delivered in 1936 in which the principal non-moving parts were of either cast steel or riveted steel plate construction; and the second, two additional units for the same destination now being completed, which are identical in every respect, except that all the large steel castings and all the riveted work have been abolished in favor of welded methods of manufacture

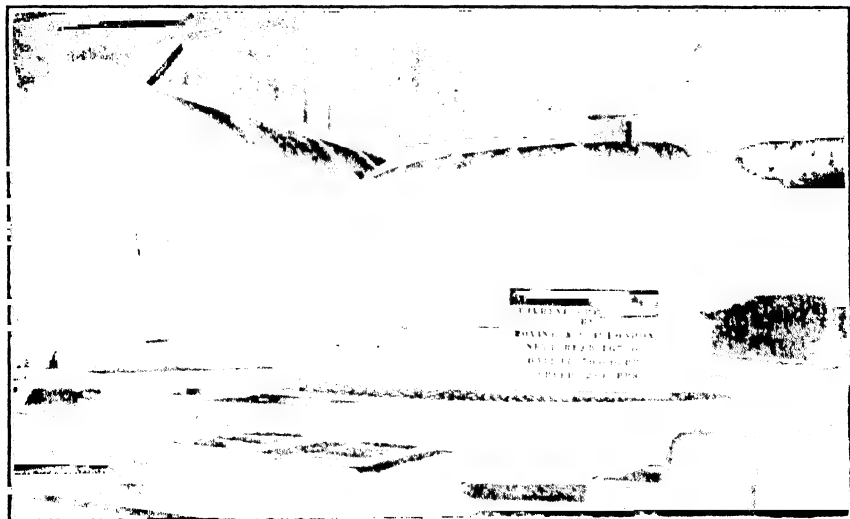



Fig. 1. The 1936

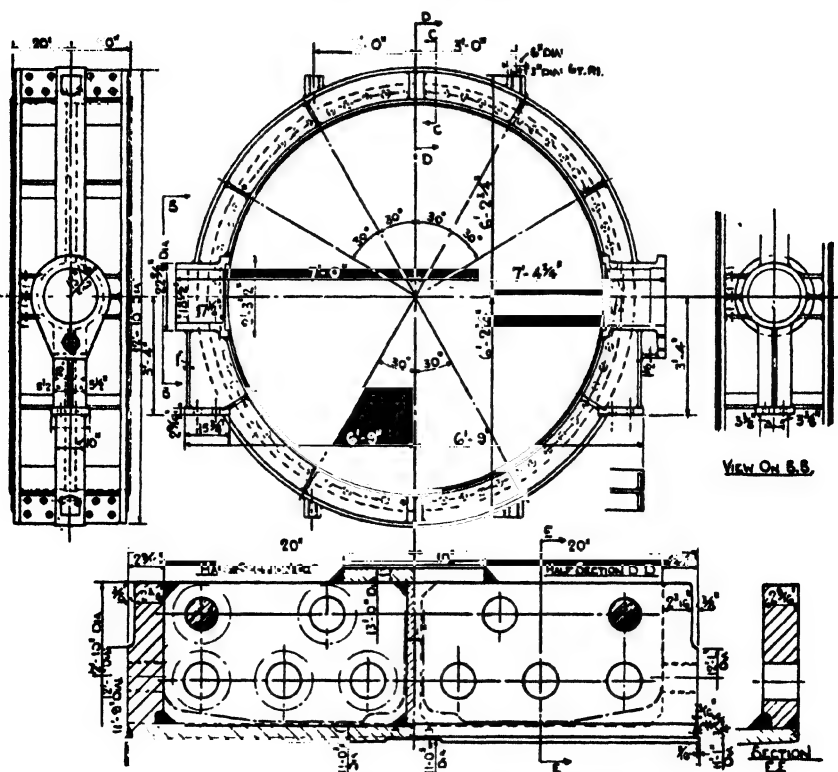



Fig. 2. Details of welded body and throttled valve, 1942 units.

Throughout this paper the two earlier turbines are described as the 1936 Units, (See Fig. 1), and the present redesigned turbines are identified as the 1942 Units.

All four turbines were ordered by one of the Dominion Governments from Messrs. Boving & Co. Ltd., Hydraulic Engineers, of London, and were manufactured to their designs by Messrs. Markham & Co. Ltd. of Chesterfield, the two firms having collaborated in this class of work for many years. The order for the second pair of turbines was placed in 1939, and the majority of the drawings of the redesigned portions were completed in the closing months of that year.

The outbreak of war shortly after this repeat order was placed, gravely affected progress, and as direct war requirements had to be given priority, work on the portions to be described was not put in hand until 1941, by which time completion of the plant had become a matter of urgency.

General Details Which Apply to All Units—The turbines described are of the vertical-shaft Francis reaction type, of conventional design, and develop 30,000 brake horsepower at a speed of 214 revolutions per minute under a head of 167 feet, and are directly coupled to A.C. generators of 24,000 kilovolt-amperes. As is usual in this type of machine, the turbine casings are built into the concrete of the foundation.

Each complete turbine consists of:

(a), Main Throttle Valve of butterfly type.
(b), Adjustable Joint with Taper Pipe between the penstock and the valve.
(c), Spiral Casing. Diameter at inlet 11 ft.
(d), Stay Ring.
(e), Covers and gate apparatus.
(f), Runner and main shaft.
(g), Relief Valve and its discharge tube.
(h), Governor and auxiliary gear.

The principal items which were redesigned for welding are (a) (b) (c) (d) and (g), but this paper is confined mainly to parts (a) and (d), since with both of these, designers and manufacturers were breaking fresh ground.

The writer, by reason of his employment with Messrs. Markham & Co., has had general supervision of the work described, and is responsible for the development and application of welding to the company's products generally.

Comparison of Methods of Construction in Original and Redesigned Units.

Item	1936 Units	1942 Units
Throttle Valve Bodies	Steel Castings	Composite construction Steel castings and M.S. plates, welded
Stay Rings	Steel Castings	M.S. plates and slabs welded
Spiral Casings	M.S. plates Riveted......(1)	M.S. plates Welded......(2)
Taper Pipes	M.S. plates Riveted......(1)	M.S. plates Welded......(2)
Relief Valve Discharge Tubes.	M.S. plates Riveted......(1)	M.S. plates Welded......(2)
Air Vessels and Governor Oil Tanks	M.S. plates Riveted	M.S. plates Welded

(1) Bolted at works, dismantled for shipment and riveted at site.
(2) Tackwelded at works, dismantled for shipment and finally welded at site.

Summarising the above, the 1936 Units incorporated no welded work, but in the 1942 Units no rivets were used and the steel castings are reduced to 30 per cent of the weight used in the earlier design, and as explained later, this figure would, but for wartime conditions, have been reduced to 10 per cent.

Reasons for Changes in Design and Construction—Whilst the 1936 turbines have proved perfectly satisfactory in service, and on grounds of efficiency and reliability there was no necessity to make any changes in design, much progress has been made in the intervening period by the manufacturers in the application of electric arc welding, particularly in the substitution of welded fabrications for steel castings. They have proved, over a period of years, that they can save time, material, and consequently money, by the judicious substitution of fabrications for a large majority of the items they have been accustomed in the past to purchase from steel foundries. Welded parts for water turbines have proved particularly successful, both during manufacture and afterwards in service. In this instance, resulting from experience previously gained, the manufacturers were able

to offer prices which made the revised designs more attractive than the originals.

Progress in Design and Manufacture—That considerable progress in the application of arc welding has been made is clear from the comparisons drawn at the beginning of the section between the 1936 and 1942 Units.

This progress shown by each portion of the turbines affected is analyzed below:

(1) Throttle Valve Bodies—Experience gained in the intervening years with welded valve bodies of diameters up to 5-feet, encouraged the designers to make the change in this case. These are the largest fabricated valve bodies on which the two firms have collaborated, bodies of this size having always previously been made in cast steel.

(2) Stay Rings—The stay rings for these turbines are the first fabricated rings which either firm has handled, steel castings always being used previously.

(3) Spiral Casings—Welded spiral casings of smaller dimensions manufactured recently having proved particularly successful, the designers had no qualms about redesigning the present examples. These are the largest welded casings either firm has handled, all previous casings of these dimensions having been riveted.

The designs, methods of construction, welding procedure, and comparisons of cost and weight for the principal parts affected are discussed in detail below.

Principal Dimensions, and Comparison between Cast Steel and Fabricated Designs—It must be understood that the throttle valves described are in no way separate items, but are integral parts of the turbine units, and are so designed that they may be operated automatically under certain conditions.

The throttle valves are of the butterfly type and the principal overall dimensions of both cast steel and fabricated designs are identical. Both bodies are in halves, being split through the vertical center line.

The following is a comparison of dimensions:

	Cast Steel 1936	Welded 1942
Diameter of Bore	11′–0⅜″	11′–0⅜″
Depth of Body	3′–4″	3′–4″
Thickness Main Flange	2⁷⁄₁₆″	2⁷⁄₁₆″
Thickness Joint Flanges	2⁷⁄₁₆″	2⁷⁄₁₆″
Thickness of Barrel	2⅛″ adjacent to flanges, tapering to 1¼″ in center	1″
Stiffening Ribs	1¼″	1″
Circumferential Stiffeners	9″ by 1¼″	10″ by 1″

By reference to the drawing, Fig. 2, it will be observed that the principal difference between the two designs lies in the barrel, which in the cast steel version had to be greatly stiffened to avoid casting difficulties which otherwise would have been experienced in an abrupt change of section between the flanges and the barrel. In addition, in order to ensure sound metal, the rib sections generally were heavier than required by purely mechanical considerations.

Neither of these two considerations need be taken into account in a fabricated design, consequently an excellent opportunity is afforded for making a reduction in weight without any sacrifice in strength or rigidity.

Details of Construction—In considering the best method to adopt for constructing the valve bodies, it was decided to make a composite fabrication, that is, steel plates and steel castings welded together The barrel, stiffeners, and flanges are designed in mild steel plate with the bosses steel castings, as these can be cast cheaper than fabricated, and only simple patterns are required.

Because of war conditions it was not possible readily to procure rolled flats of the section necessary for the flanges, the rolling mills being fully engaged for long periods ahead on the production of standard sections It was decided therefore, to make the four flanges from a solid cast steel ring 13-feet, 0-inches outside by 10 feet, 10 inches inside diameters and 16 inches wide, the flanges being parted off in the lathe and sawn in halves

This, as will be seen later, was an expensive alternative, but the only one possible under the conditions

Fig. 3. Two halves of welded body for 11 foot diameter throttle valve, 1942 units.

Manufacturing Procedure—The assembly of the half valve bodies was a straight forward operation and calls for little comment Stays of light joist section were welded across the open ends of the barrel plates after these had been rolled to the correct radius, in order to prevent alteration of dimensions during assembly and welding The half flanges and the bosses, previously machined to within ⅛-inch of finished sizes, together with ribs and stiffeners, were all tack welded into position, and the whole of the assembly work completed before any final welding commenced

One run with a ¼-inch diameter electrode was put down at the back of the flanges to stop the tendency of these to distort during the welding of the inside groove, 5/16-inch diameter electrodes being used for the weld between the barrel plate and the flanges, and fillet welds were built up with ¼-inch and 5/16-inch electrodes for the back of the flanges and all stiffeners. Two runs were used round the flanges and bosses, and one run elsewhere.

Comparison of Weights—Throughout this paper weights are given in terms of tons of 2000-pounds.

Weight of 2 cast steel half bodies before machining........................13.25 tons
Weight of 2 fabricated half bodies, (See Fig 3), unmachined... .....11.5 tons

a reduction of 1.75-tons per valve body, or 13 per cent as compared with the cast design.

Stay Rings—Whether manufactured as a steel casting, (See Fig. 4), or a fabrication, (See Fig. 5), the stay ring is a complicated and costly item. It must be of great strength and rigidity since it is the foundation ring around which the whole of the turbine is constructed.

In the present examples the principal dimensions are common to both designs, the inside diameter being 11-feet, 3-inches and the outside 14-feet, 9-inches, with an overall depth of 6-feet, 0-inches. Both rings are made in halves.

Reference to Figs. 6 and 7 will illustrate the general design, Fig. 7 showing the difference in section between the cast steel and fabricated designs, and it will be noted that whereas the latter is mainly built up of 1¼-inch plate, the corresponding sections of the former are 1⅜-inch thick.

This design is a good illustration of the possibilities of weight reduction without sacrifice of strength or rigidity which may be achieved when redesigning for welding.

Details of Construction—In both designs twelve stays equally pitched, connect the upper and lower lips of the ring. These stays, 3½-inches thick in the cast steel design, are reduced to 3-inches thick in the fabricated ring. The lip rings are cambered at an angle which varies progressively round the circumference to meet the varying diameters of the spiral casing. In the fabricated design the stays pass through the lip rings for the full depth of 5-feet, 11-inches, thereby adding to the weight, but serving to anchor the ring into the foundations very securely. The circular rings which form the flanges to which the gate apparatus covers are bolted are welded to vertical rings which are slotted to fit over the tops of the stays, and both rings are welded to the stays, and thus it will be appreciated that the design is a particularly strong and rigid one.

The arrangement shown in Fig. 7 for the welding of these vertical rings to the joint flanges should be noted. Grouting holes are provided between each stay in the lower lip ring to facilitate concreting at erection, cover plates being provided for these holes which will be welded in and ground off flush on completion of erection.

Manufacturing Procedure—The manufacture of these rings presented some problems, principally because of the changing cambers of the upper and lower lip rings to match the variations in diameter of the spiral casing. Reference to Fig. 6 shows that each lip ring was built up in eight segments, which are numbered on the drawing 1 to 8 in the lower ring and 1a to 8a in the upper ring.

The plates forming the rings are 1¼-inch thick, and as each pair of plates in upper and lower rings are symmetrical they were pressed in pairs between vee-shaped blocks in a 150-ton hydraulic flanging press. The photograph, Fig. 8, shows one pair of the blocks with two views of the pressed plates. The plate on the right is marked to show the shape of the segments as welded into the rings.

In all, four pairs of these blocks were cast, being moulded in loam from skeleton patterns. Three pairs of the blocks were used to produce 28 segments of upper and lower rings, the fourth pair of blocks being specially made for the four plates required to match the casing inlet at the large end of the scroll.

After a pair of blocks had been used to press one pair of segments, the

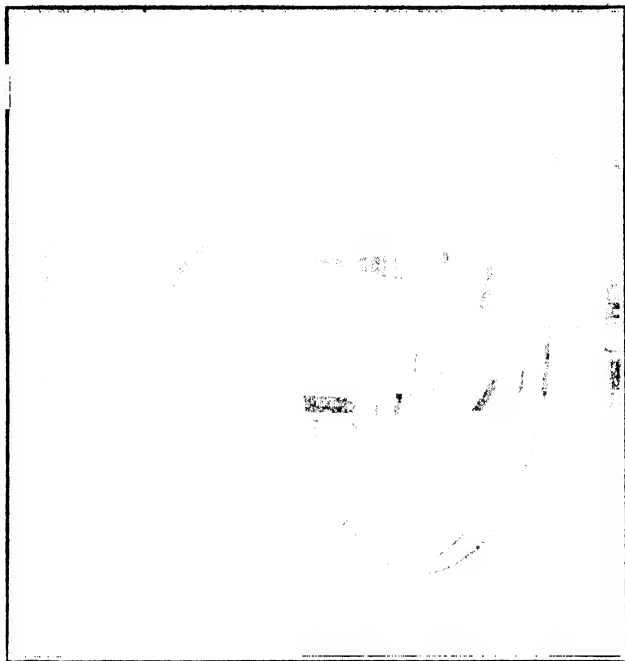



Fig. 4. Cast steel stay ring, 1938 units.

shape was altered by machining out the female block and affixing plate packing pieces to the male block in order to press the next pair of segments, and in this manner the cost of the blocks was kept at a reasonable level. As a result, Block No. 1 was used for plates 1 and 1a, 2 and 2a, 3 and 3a, in Fig. 6, (12 segments), Block No. 2 for plates 4 and 4a, 5 and 5a, (8 segments), and Block No. 3 for plates 6 and 6a, 7 and 7a (8 segments).

After all the plates had been pressed they were marked out and gas cut to the shape required and bevels for welding were planed at either end.

The stays were pressed to the correct curvature and the necessary radius planed on either edge. The steps at each end were then gas cut and machined. This will be noted in the sectional view Fig. 7.

In the meantime the lip plates were assembled on a level table, clamped down, and tack welded together as complete rings, omitting the joint flanges. Incidentally the good work done at the hydraulic press was here revealed since the amount of adjustment of the plates required to keep the contours of the rings correct was negligable.

The tack welding finished, the slots for the stays were marked out and gas cut, and at the same time the vertical rings carrying the upper and lower flanges were slotted by gas cutting to fit over the tops of the stays. These, along with the radial stiffeners at the back of the lip rings were tack welded into position on the lip rings before releasing them from the clamped position.

In view of the high stress transmitted by each of the stays great importance was attached to ensuring that the stays themselves were an accurate fit in the holes cut for them in the lip rings. For this purpose wooden models of the stays were made and the holes in the lip rings chipped to fit them. At the same time the holes were beveled on both sides for welding.

The procedure adopted for the assembly together of the ring and stays, was first to level and clamp down the lower lip ring to a table. The stays were then inserted into the prepared holes, and these after squaring up and checking for pitch were tack welded into the ring.

The upper lip ring was then lowered into position over the stays and straining screws attached at intervals round the circumference in order that the ring could be pulled steadily and without risk of distortion into its correct position. Next, the top and bottom main flanges, smithed to shape in halves and machined to correct outside diameter, were tack welded into the assembly.

After a final check of dimensions, during which each ring was marked out for machining, the welding was started by welding the upper bevel at each of the lip ring joints and the downhand welding of the stays at top and bottom.

The ring was then turned over and the welding on the opposite side of these joints completed, care being taken that full penetration was obtained at each joint by exposing by chipping, the weld metal previously put down.

On completion of these welds the ring was turned on edge in order that the welds on the inside circumference could be completed in a downhand position, the ring being turned as required, and at the same time the fillet welds of the external stiffeners were completed.

The rings were completed by splitting into halves and fitting and welding the joint flanges.

Two welders were employed, working diametrically opposite to one another in order to ensure even distribution of the heat set up by welding, and thus reduce the possibility of distortion, and to check this point the principal dimensions were tried over daily during the progress of the welding, but no distortion was observed at any time.

Comparison of Weights—Weight of 2 cast steel half stay rings, unmachined .... 17.35 tons.
2 Fabricated half stay rings, unmachined........................ 15.1 tons.

This gives a reduction in weight of 2.25 tons per stay ring, or 13 per cent as compared with the cast design.

Spiral Casings—The general dimensions of both designs are identical, the diameter of the casings at the inlet being 11-feet, ⅜-inches, the maximum dimensions overall being 32-feet, 0-inches by 31-feet, 0-inches, and because of these sizes both casings were designed to be assembled complete in the shop, match marked, and then dismantled for shipment plate small, for final riveting or welding at site.

The plate thicknesses in both designs are alike, commencing at the inlet with 11/16-inch plates, thicknesses being reduced gradually as the scroll narrows, to ⅝-inch, ½-inch and ⅜-inch at the small end. The rivets in the 1936 casings were 1-inch and ⅞-inch diameter, countersunk on the inside of the casing, with single riveted circumferential, and double riveted longitudinal seams, the connections to the stay ring being triple riveted at the large end, and double riveted at the smaller diameters.

In the 1942 casings, the welded circumferential seams are all single beveled, on the outside of the upper part of the casing and on the inside of the lower part, this is done to simplify the welding at site, so that the bulk of this may be done in the downhand position.

The amount of staggering of adjacent longitudinal joints in the riveted casing will be noted by reference to Fig. 9. This has been reduced to 6-

inches in the welded job. In the welded design the connection between the casing and the stay ring is butt welded as compared with the riveted lap joint of the earlier design.

In each casing a branch 6-feet in diameter is taken off to the relief valve. In the riveted casing this was flanged and double riveted to the casing through a stiffening ring. In the welded design the branch is welded directly to the stiffening ring, which in turn is welded to the casing at site.

The 11-feet, 0-inches diameter inlet flange is, in each case, of cast steel, and provision is made in the casing for a man-hole, bypass branch, and air valve and drain branches.

Riveted Casing—The principal operation imposed by this design and calling for comment, is the large amount of hand drilling with pneumatic machines which was required during shop assembly. To ensure fair rivet holes in the circumferential and longitudinal seams, only the inner plate of each lap was marked and drilled in the flat, the outer plate being air drilled through this after assembly. The holes for the riveted connection between the stay ring and the casing plates were also drilled through both items after assembly. All this was a rather lengthy and costly operation.

Welded Casing—The only changes in shop procedure in the welded design are that the air drilling is not required, neither is it necessary to scarf one plate edge as in the riveted lap joints.

Since both specifications call for the casings to be broken down for shipment, this effected a considerable saving in both time and money.

Comparison of Weights

Shipping Weight of 2 Riveted Casings

Weight of plates etc	49.7 tons	
Weight of rivets	4.9	
Total	54.6 tons	54.6 tons

Estimated Shipping Weight of 2 Welded Casings

Weight of plates etc	49.7 tons	
Less plate at lap joints (estimated at 5-tons per case)	10.0	
	39.7 tons	
Plus allowance for rivet holes not required	1.7	
Total	41.4 tons	41.4 tons
Saving in weight		13.2 tons

The above figures show that the saving in weight achieved by the substitution of welded construction for riveted amounts to..................24 per cent.

Relief Valve Discharge Bends—As mentioned in Part 5, the spiral casings carry a branch pipe of 6-feet internal diameter to which is connected the relief valve, (See Fig. 10). As the name implies, the function of this piece of apparatus, which is controlled from the turbine governor, is to prevent a

dangerous rise in pressure in the penstock and casing should the load suddenly be thrown off the unit. From the bottom of this valve a right angle bend pipe constructed of mild steel plate conducts the discharging water to the tail race.

Principal Dimensions and Comparison of Designs—The leading dimensions are:—
Inside diameter 8-feet, 3-inches. Distances from vertical center line to outlet flange, and from horizontal center line to inlet flange are both 8-feet, 2-inches. The pipes are constructed throughout in lobster-back form from 1/2-inch plate with angle flanges of 4-inches x 4-inches x 1/2-inch section. There is nothing about the design which is not familiar to fabricating shops accustomed to the manufacture of large diameter pipework.

The bend pipes supplied with the 1936 turbines were of riveted construction throughout, using 7/8-inch diameter rivets countersunk on the inside and single riveted lap joints, and were shipped plate small after assembly in the shop. On erection at site and after riveting, the plate edges at the lap on the inside of the pipes were fillet welded round in order to smooth off the interior surface and to assist in preventing corrosion.

The pipes for the 1942 Units are of welded construction throughout, all the plate joints being butt welded, with the two angle flanges fillet welded at either end. These pipes have been completely erected in the shop, and will be shipped plate small for final welding at site, and in this case also site welding is probably likely to be more satisfactory than site riveting.

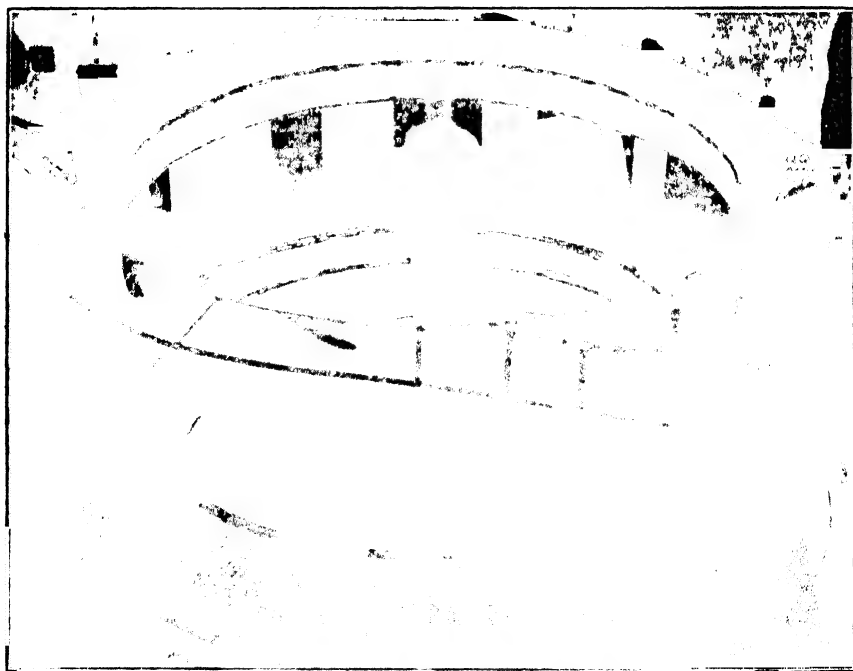



Fig. 5. Welded stay ring, 1942 units.

Comparison of Weights

Shipping Weight of 2 Riveted Pipes

Weight of Plates etc.	9.9 tons	
Weight of Rivets	.9 "	
Total weight	10.8 tons	10.8 tons

Shipping Weight of 2 Welded Pipes

Weight of Plates etc.	7.2 tons	7.2 tons
Saving in weight		3.6 tons

The percentage saving in weight realized by the substitution of welded construction is .... 33 per cent.

Taper Inlet Pipes and Adjustable Joints—These parts are situated between the lower end of the penstocks and the throttle valves. The diameter at the end of the penstock is 12-feet, 0-inches, and that at the valve 11-feet, 3/8-inch, and this taper pipe connects the two. It is 4-feet, 1/2-inch long. At the large end there is a short adjustable joint and gland, the purpose of this being to provide the necessary amount of axial movement to free the valve during assembly or overhaul.

In the 1936 Units, the female portion of the adjustable joint was riveted to the end of the penstock, and the male portion riveted to the taper pipe, which in turn was entirely of riveted construction.

In the present units, however, no rivets are used, all connections being welded. Here again the parts are shipped to site plate small after erection and marking in the shop.

It is not proposed to quote figures of costs for these items, since they possess no special features. They are mentioned to emphasise the completeness of the changes in design and construction throughout the 1942 Units.

Quality Control—All the welders employed on the work were fully experienced and reliable men. It should be recognized however that even the best of welders cannot produce good work unless the preparatory work is of an equivalent standard. Inspection therefore resolves itself under three main headings:—

(a) Inspection of the assembly before welding is commenced.
(b) Inspection of the work whilst welding is in progress.
(c) Inspection of the work after completion of welding.

Inspection of Assembly—It is no exaggeration to say that the bulk of the troubles encountered in welded work may be traced back to faulty assembly. Particular importance should be attached to this, and welding, apart from the tacking required during the assembly should not be allowed to commence until the complete structure has been assembled as far as possible, the beveling and fit of the plates inspected, dimensions checked over, and the welding sequence studied so as to minimize the effects of contraction.

Butt Welds—The importance of maintaining sufficient gap between the plates to ensure complete penetration should be stressed, at the same time

observing that the gap should not be so great that it cannot be bridged with the first run. The need for leaving a gap sometimes complicates the work of assembly and there is consequently a strong temptation to butt plates closely together.

The difficulty may be overcome by inserting narrow strips of sheet steel or plate of the required thickness at intervals between the abutting plates during assembly, and these will also prevent the plate edges from being drawn together by contraction as the welding proceeds. If it is found that these become so tightly gripped between the plates that they cannot be withdrawn, they may be cut off short with a chisel and welded over.

Too much jacking or straining to bring plates into line with one another should not be permitted. In large fabrications a certain amount of this may be unavoidable, but it should be borne in mind that this practice, if not kept strictly within limits, will set up undesirable residual stresses in the finished work.

Fillet Welds—In fillet welds connecting two plates at right angles a close butt is often desirable. This is not always easy of attainment, but it should nevertheless be insisted upon before welding is allowed to proceed.

Inspection During Progress of Welding—Even when the operators are well known to be skilled at their work this part of the inspection should still receive the maximum of attention.

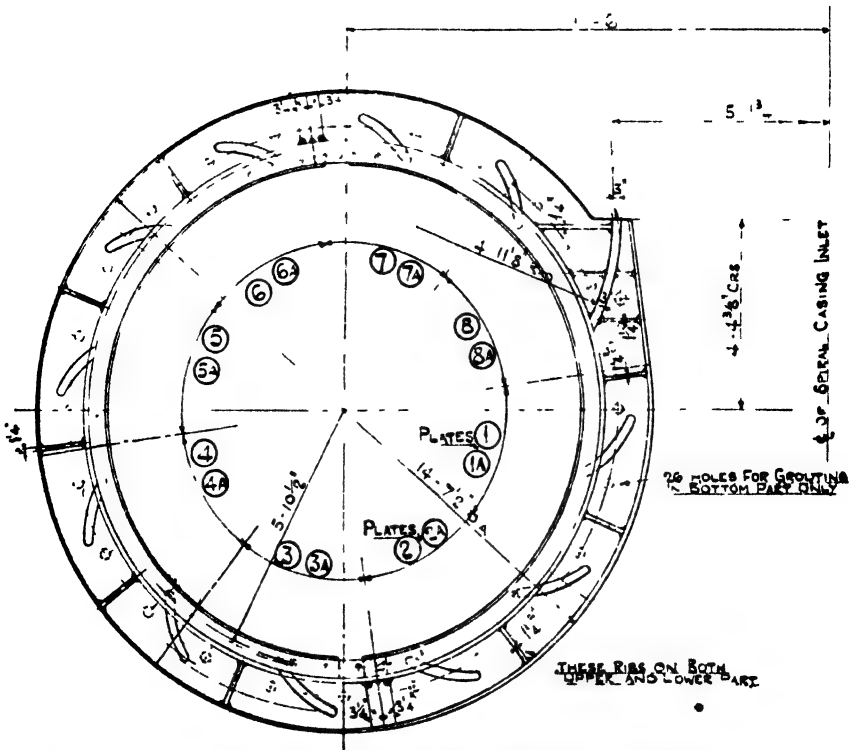



Fig. 8. Plan view of welded stay ring for 30,000 horsepower water turbines, 1942 units.

The faults which may be encountered may be summarized as follows:—

(1) Excessive undercutting.

(2) Poor penetration.

(3) Slag, dirt, or gas inclusions.

(4) Irregular appearance.

The first is most frequently to be observed in the vertical member of a fillet weld, and in pressure work particularly is a serious fault, since the section of the welded parts is reduced locally, leading to a concentration of stress, which, if the reduction of area is severe may assume dangerous proportions. Similarly, in mechanical parts, concentrations of stress at a sharp corner provide starting points for fatigue cracks.

This trouble is usually caused by the use of an unsuitable electrode, or by incorrect manipulation, or by the use of too high a current, but there are many electrodes obtainable at the present time which are specifically intended for fillet welding, and good results are readily obtainable, particularly in D.C. work, provided the maker's recommendations regarding polarity and manipulation are observed.

The second fault, poor penetration, is caused by the operator not having sufficient control over the molten pool, and provided the electrical connections are good, is nearly always the result of low current.

This will be evidenced by "overlap" of the bead, inadequate root fusion, and rough finish. The operator's attention should be drawn to the fact that his efforts will be greatly simplified, and will give better results, if the amperage is raised to the correct value.

On the other hand too high a current will give a fierce crackling arc, the electrode may become red hot, considerable "splatter" of tiny globules of metal will be observed round the welded area, and the resulting weld will probably prove to be porous.

Given an electrode by a reputable manufacturer the third fault, inclusions of slag, dirt, or gas, is quite inexcusable and can only be caused by incorrect manipulation by the operator or by his failure to clean the work before commencing welding and between welding runs.

It is important that the length of the arc should be kept as short as possible without the electrode coating being in contact with the molten pool. A short arc reduces the possibility of atmospheric contamination, particularly when electrodes of the gas shielded type are not employed, and by localizing the heat it assists penetration and ensures a neat finish to the work.

The fourth fault of irregular appearance, refers particularly to fillet welds, where it is important that each "leg" of the fillet should be equal. Much can be done to ensure this by the use of the correct grade of electrode and by positioning the work so that the electrode can always be held in a vertical plane.

The contour of a weld of this type should be slightly convex. If one leg is longer than the other the cause may prove either to be incorrect manipulation of the electrode, failure to position the work, or the use of too high a current.

Inspection after Welding—In any visual inspection of the work after welding particular attention should be paid to any corners at which the seam changes direction. When pressure work is concerned these are the usual places at which to expect porosity, for this may be caused by the welder finishing one run in the corner and then completing the seam from the other direction, both runs meeting in the same corner. The craters left at the ends

Fig. 7. Sections of welded stay ring, 1942 units.

of the runs usually prove to be porous, and are a familiar source of trouble when the completed job is hydraulically tested.

Where three welds meet at a "T" the forgoing procedure should be followed with two of them and the third should start from the joint of the "T" and work away from it.

Similarly, when welding round the ends of ribs of stiffeners, the operator should not be allowed to break the arc at the change of direction.

Testing—The forgoing remarks outline the general principles governing the inspection procedure on the parts described in this paper. No special tests of the welding itself were required, but as a matter of routine each welder is supplied with a steel stamp bearing an identification letter with which to mark his work, and each welder is required at intervals to complete a "nick-break" test piece.

Although this test does not present any difficulty to experienced operators it is particularly useful in grading new-comers, proving as it does, whether or not the operator is capable of laying down a neat run free from inclusions, and obtaining adequate penetration and fusion at the root.

In the case of the Throttle Valve Bodies the quality of the work was proved by subjecting the finished bodies to a hydraulic test pressure of 130 pounds per square inch for 30-minutes. Fig. 11 shows such a test in progress on one of the 1936 cast steel valve bodies.

In the case of the stay rings, it will be appreciated that no such positive test is possible in the shop and for that reason every precaution was taken by close inspection during manufacture to ensure that the quality of the work was of the highest class, and the writer is confident that the workmanship put into these rings would be difficult to improve upon.

Advantages of Welded Construction—The particular goal towards which every designer of heavy engineering plant which has to be sold in a competitive market should strive, is to effect a reduction in weight without sacrificing strength and rigidity, and without impairing the efficiency of the finished product. A reduction in weight of primary materials implies an all around reduction in material, labor, handling, and transport costs, and is more than ever desirable when the completed plant has to be shipped overseas.

In the present examples, the adoption of welded methods of construction has contributed to a reduction in weight in an outstanding fashion, as will be seen from the figures given below.

	1936 Units (Cast Steel)	1942 Units (Fabricated)
2 Throttle Valve Bodies	26.5 tons	23.0 tons
2 Stay Rings	34.7	30.2
2 Spiral Casings	54.6	41.4
2 Discharge Tubes	10.8	7.2
Totals	126.6 Tons	101.8 Tons

This gives a total reduction in weight for the two 1942 turbines as 24.8 tons, or 20 per cent of the weight of the 1936 units. This is a factor of great significance even in normal times since in addition to the savings in transport, freightage, and handling costs previously mentioned, it is an economy of value to industry in general as it means a saving of the raw materials which are necessary for the production of finished steel.

In time of war the importance of this economy in the use of raw materials and finished steel does not need emphasizing, particularly to people in this country where the use of steel has been rigidly controlled by the government since the outbreak of war, and where we have seen nation wide drives for scrap metals, the wholesale uprooting of iron railings from our streets, and the thorough recovery of steelwork during the demolition of "blitzed" buildings.

Indeed, it is not too much to say that the redesigning of these turbines was justified if for no other reason than that 25 tons of finished steel, and the labor required for its production, was thereby released to assist the country's war effort in other directions.

Secondary Advantages—Welded construction offers other advantages to the manufacturer, the principal one being the saving in time, and general quickening of production which it makes possible. This is particularly marked in cases where welded fabrications are substituted for steel castings.

In the heavy engineering industry the promised delivery date for steel castings is the datum from which the machining and delivery program must be arranged, and adjustments of the program caused by non-delivery of castings, or perhaps due to defects discovered during machining operations, cause much disorganization and loss of valuable time, and are a source of irritation to customers.

It is not surprising therefore, that the substitution of welded fabrications

for steel castings has received a great deal of attention from engineering concerns who are sufficiently well equipped with the plant necessary for the manipulation of plates and sections. Here, using standard material, the plating shop program may be correlated with that of the machine shop, and delivery dates given to customers with every confidence that, barring extraordinary occurrences, they will be maintained.

In a works manufacturing its own fabrications the extra work involved in fabricating and welding will bear its proportion of the overhead expenses, and by spreading these over a greater volume of completed work will assist in keeping them at a reasonable level.

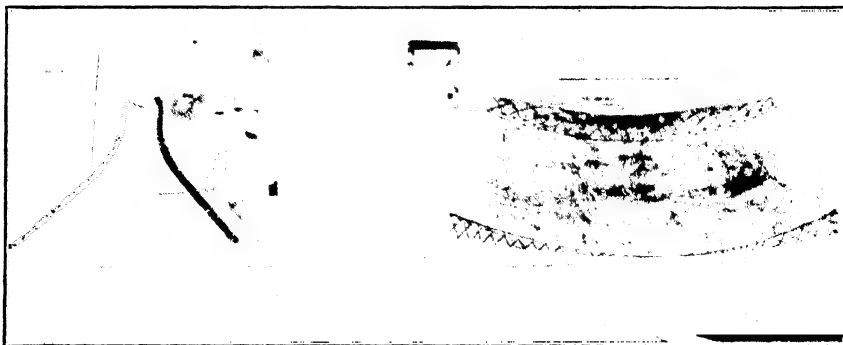



Fig. 8. Press tackle used in manufacture of welded stay ring, 1942 units.

No troubles will be experienced such as those caused by defective castings requiring replacement, perhaps after considerable costs have been incurred in their machining, and it is not surprising that many firms, including the writer's employers, now regularly fabricate many items which in the past would automatically have been purchased as steel castings.

Summarized therefore, the secondary advantages offered are:—

(1) Overhead charges spread over a greater volume of work.

(2) No internal disorganization caused by delays in deliveries from external sources.

(3) Faulty castings discovered during machining operations may have to be rejected, but faulty work in fabrication, if found in time, is more readily put right than in a casting.

(4) In cases where special efforts must be made to meet customers' delivery requirements, the whole of the work, being confined to one organization, may be kept under the supervision of the executives ultimately responsible for ensuring that these requirements are met.

With regard to repairs by welding, mentioned in (3) above, this kind of work has, even in the best cases, the stigma of a patch attaching to it in a casting; but this is not so with a fabrication as the repair has been done by the original manufacturing process.

This feeling is in many cases purely psychological, but nevertheless it is of importance with most customers.

Technical and Social Advantages—The advantages which may be expected to accrue from the general adoption of welded methods of construction to large water turbines of the type described are discussed under the three headings of service life, efficiency, and social advantage.

Service Life—There is as yet little data available upon which to base any estimate of increase in service life to be expected from the welded parts which have been substituted for the cast steel parts of the 1936 Units, and there is no reason to suppose that the change will result in any increase of service life, but on the other hand there certainly will be no reduction of it.

The position of the riveted parts is another matter, since lapped plate joints and rivet heads are particularly susceptible to the effects of corrosion, and it is reasonable to expect that the smooth finish, both of interior and exterior surfaces of the welded spiral casings, inlet pipes, and discharge tubes will prove more resistant to the effects of corrosion than the riveted designs, and consequently the service life of these parts will be prolonged. It may be noted also that the patching by welding, of worn places due to wear, corrosion or cavitation, may be done with somewhat more confidence to parts which have been fabricated than to others, particularly to castings.

Efficiency—The modern water turbine is the most mechanically efficient prime mover in existence, but it has only attained that position by reason of research work and careful attention to detail in design extending over a period of many years.

In tendering for work of this description the efficiencies which the designer expects to achieve have to be guaranteed, and it is usual by the conditions of contract, to impose heavy penalties in the form of liquidated damages for any failure to attain the guaranteed figures during running tests at site.

Indeed, so much stress is placed on this aspect that it is not at all unlikely that in a great many instances the turbines for major schemes are purchased, not on price, but on the maker's guaranteed efficiency figures.

The reason for this is readily appreciated when it is borne in mind that in the average hydro-electric scheme the cost of the turbine itself forms a very small proportion of the cost of the works, in many cases not exceeding 5 per cent of the total.

Any increase in turbine efficiency therefore, enables just so much more electrical energy to be developed from a given quantity of water, and thus the increased earning capacity of the plant will justify the additional cost (if any) incurred by the installation of the most efficient turbine that can be obtained.

For these reasons in all hydraulic machinery and in water turbine practice particularly, the greatest importance is attached to making all surfaces in contact with the water smoothly finished and free from irregularities of contor, since neglect of these matters will increase the losses due to skin friction, and will also cause turbulence in the water passing through, and thus will reduce the efficiency of the machine.

The importance of this question of surface finish will be seen when it is realized that the loss of 1 cusec of water per 100-feet of head is the equivalent of a power output, which if sold at only 0.85 cents per kilowatt hours would amount to over $500 in a year, so in the turbines described in this paper, operating as they do at 167-feet head, the reduction in earning capacity caused by the loss of 1 cusec would amount to $835 per machine per annum.

It appears reasonable from this to expect, all other things being equal, some increase in the efficiency of the present units as compared with those of 1936, since in the spiral casings the increased smoothness of the interior which follows on the adoption of welding, should by comparison with the riveted casings reduce the hydraulic losses.

When considering the throttle valves and stay rings it will be realized

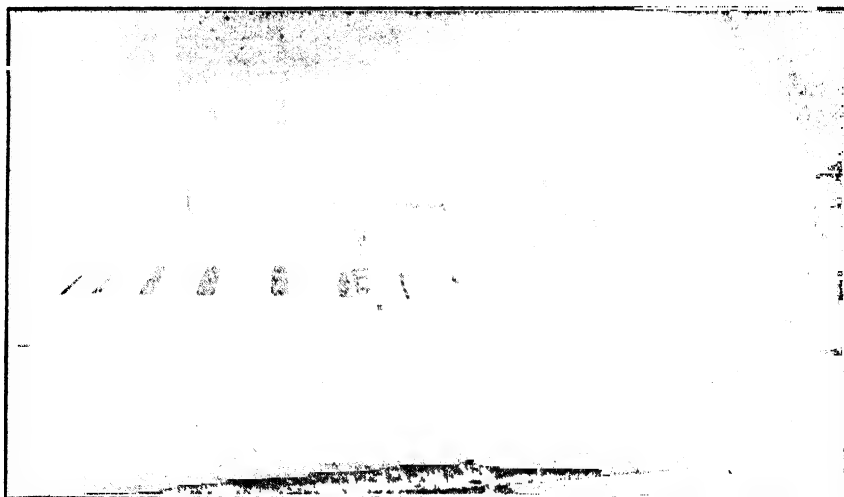



Fig. 9. Shop erection of a spiral casing, 1936 units.

that the surface finish of the water spaces obtained in the fabricated examples by the use of rolled steel, is much superior to that of cast steel. There is indeed little comparison in surface finish between a good mill finish of a rolled plate, and the surface left by the sand in even the best of steel castings, and from this point of view there can be no doubt which method of construction is the more suitable for water turbines.

The designers naturally base their guaranteed efficiencies on proved grounds, prefering for the moment to regard such improvement in efficiency as may be achieved from fabrication as purely fortuitous.

Judging from recent experience gained on similar work, there are good grounds upon which to base this expectation of improvement. In any case the installations at this site will offer an exceptionally excellent example for comparative tests.

Social Advantage—The previous sub-section leads to the question of the ultimate value to mankind in general of the adoption of welded methods of construction to all water turbines, and particularly to those of the reaction type.

There can be little doubt that, in spite of the great hydro-electric projects which have been completed in recent years, the world as a whole is still far from making the fullest use of the natural resources of water. It has been estimated that less than 10 per cent of the available resources of the world are at present being utilized, and although it must be remembered that some of these potential resources are not at the present time capable of economic development by reason of the limitations imposed by their geographical situation, yet we must not expect these limitations to prove insuperable in the future.

Already the presence of ample supplies of water at the necessary elevation has a tremendous influence on the prosperity of mnay countries, and as time goes on the maximum development of these resources will become of increasing importance. Here nature has provided in perpetuity, a complete cycle which will continue long after all the coal and oil in the world has been exhausted and as long as the solar cycle continues.

Water when harnessed for power purposes is not consumed, it is regenerated by the sun by being raised in the form of vapor from sea level to mountain tops; but the generation of power by the consumption of solid or liquid fuel means that every pound so burnt is irretrievably lost, a loss not only of interest but of capital also.

Already we have been told that the present generation will see the beginning of the end of the world's oil resources as we know them at present, and although both in the British Isles and the United States the coal reserves are ample for many generations to come, yet it is still important that these reserves should be husbanded, and that we must look to water power as a substitute for coal in increasing measure as coal becomes more difficult to win and consequently more expensive.

How far we have proceeded towards full utilization of water power resources will be seen from the following figures:

	U.S.A.	Canada
Approximate potential water power........	48,000,000 H.P.	43,700,000 H.P.
Developed at Jan. 1st, 1941...	18,868,027 H.P.	8,584,438 H.P.

This means that approximately 29 per cent of the total water power resources of the North American continent have as yet been utilized.

The percentage is only slightly higher in Europe, although there are

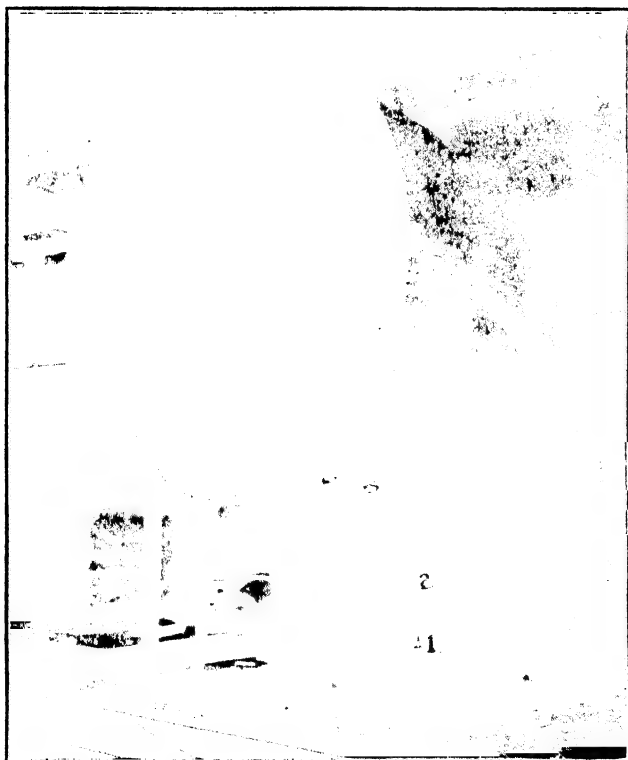



Fig. 10. Relief valve discharge tube, assembled for inspection, 1942 units.

several countries, notably Sweden and Switzerland, whose prosperity depends to a large extent on their natural resources in water power.

The utilization of the water resources in the British Isles has not made comparable headway, partly due to the abundance and quality of the coal measures and partly due to geographical limitations, and although several interesting power schemes have come into operation in recent years, there is ample scope for considerable expansion.

It will be seen therefore, that in many directions there is room for further development in the application of arc welding to the manufacture of water turbines, since in this field it offers opportunities for reduction of cost, increase in efficiency, acceleration of manufacture, and economy in the use of materials, advantages of importance not only to manufacture, but to progress generally, and the social life of mankind, of which manufacture is the humble servant.

Conclusion, Welding in War and After—Just as the World War of 1914-1918 gave a tremendous impetus to the design and manufacture of aircraft and motor vehicles, and added greatly to knowledge of wireless telegraphy, and brought changes in its train which have revolutionized the daily life and social outlook of millions, so we must look for similar vast changes arising as a result of the present conflict.

What will be the form these changes will take is still obscure, but it is clear that the engineering industry must be prepared to meet heavy demands in the vast reconstruction programs which must be put in hand when the war is over.

Just as engineering production will ultimately be the deciding factor in war, so increased productivity at lower costs will be essential for the rapid recuperation after the war of a world impoverished by the struggle, and the obvious way to increase production is the more vigorous organization and fuller use of the facilities already to hand.

The application of arc welding for example, has been greatly stimulated by the intensive production efforts which the war has enforced. Drawings of components involving the use of rivets, drop forgings, and steel castings, hitherto regarded as sacroscant, have hurriedly been withdrawn, and replaced by simplified welded alternatives.

One such component, for a gun mounting, which will serve as an example, involved as originally issued the use of 4 drop stampings, 2 plates, 3 steel pressings, 38 tubular distance pieces, 37 rivets, and 4 bolts and nuts, reappeared, looking it is true somewhat shorn but no less efficient for its purpose, and fabricated by welding from exactly seven pieces of plate. This is only one example out of many.

That a world war should have been necessary to bring about common-sense changes of this description is a saddening reflection, and the inference is that many designers have not made themselves sufficiently acquainted with the progress which has in recent years been made in the application of arc welding methods, and that only the inexorable demands of war production have been able to break down the barriers of convervatism which have hampered the development of a manufacturing process which is steadily revolutionizing the engineering industry.

It should be understood that the writer is not one of those persons who would weld anything and everything, on the contrary it is his opinion that in the past more harm than good has been done by over-enthusiasm in the application of arc welding. There is however a tendency with any new

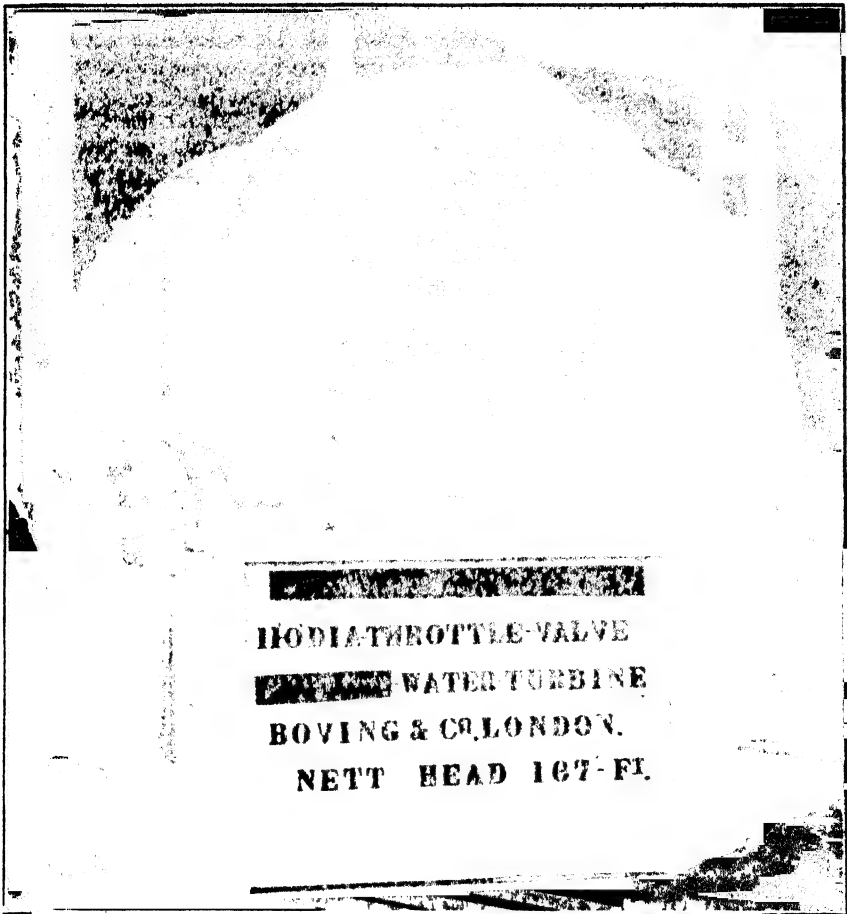



Fig. 11. Cast steel throttle valves, 1936 units.

technique to apply it in cases where its use is not economically justifiable or its particular advantages entirely applicable, or it might be more correct to say, in some cases, without having first acquired a sufficient control over the quality of the product

When normal conditions return, the steel foundries will not be doomed to extinction, the humble rivet will still continue to play its useful part in production, and there will be room for all methods of production to have full scope, but it is in the field of design that the flexibility and economy which arc welding makes possible will have to be more fully realized and in this direction there is room for much educational work amongst Drawing Office staffs

In this connection it may be significant to note that the first booklet to be issued by an Advisory Service in Welding, which has been set up by the British Government, is intend primarily for the use of Drawing Offices and deals with arc welding methods and the use of symbols on drawings

Thus it is clear that the necessity for training draftsmen to think in terms of fabrication by welding, is becoming increasingly recognized, as it is

acknowledged that the successful application of welded methods is chiefly a matter of design, and that this presents unlimited opportunities for original thought, whilst the prospect of any revolutionary changes in the design of cast or riveted parts is remote.

There is probably no field of design in which these opportunities are greater than in structural steel-work where owing to the standardization of sections and details, new developments have been rare, and it is here that we shall probably see the greatest progress after the war.

Welding has given a new freedom to structural design, and no other method of construction presents such extensive possibilities of material economy, though it is difficult for draftsmen educated and trained in riveted design to avoid improvising on existing riveted details, and many have still to be convinced that the design of a structure in which welding is merely substituted for riveting as a means of connecting the various members is entirely wrong and has little to recommend it technically, economically, or artistically.

The golden rule in a welded design for either structural or mechanical purposes, is that welding must not be done for the sake of welding. If it is possible conveniently to bend or fold the material, and so dispense with a welded joint, so much the better, for this is the direct way to a cheaper and neater finished article.

The examples given in this paper will be recognized as forming part of an engineering project of major importance. The fact that such extensive redesigning was possible after an interval of only three years is a direct measure of the designer's adaptability and the progress made by the manufacturers in the application of arc welding methods. There can be no doubt that, with the return of peace and the resumption of normal trading conditions, the experience gained as a result of this work will be of considerable value to both firms concerned, and it is the author's hope that perusal of the results achieved may encourage others to investigate, more fully than in the past, the possibilities of arc welding in the design and manufacture of their products.

The author desires to acknowledge the courtesy of O. Thott Esq., Managing Director of Messrs. Boving & Co. Ltd. London, in permitting the use, for the purposes of this paper, of the examples given.

He also wishes to express thanks to Messrs. R. J. Barclay, and F. Williams, respectively Managing Director and Works Director of Messrs. Markham & Co. Ltd. Chesterfield, for helpful criticism and permission to incorporate the photographs.

Chapter VII—Welding of Finished-Machined Casting

By Carlton G. Lutts and Paul Ffield,

Materials Engineer, Navy Yard, Boston, Mass., and Materials Engineer, Bethlehem Steel Co., Quincy, Mass., respectively

Carlton G. Lutts

Subject Matter: Repair welds on castings used to be considered unsatisfactory, but improvement in welding technique, particularly in the use of coated electrodes and the development of specialized methods of making heavy welds have dissipated former anxieties. This has led to the building of turbine casings from three separate castings, welded into a single unit —a procedure which results in lowered costs and a superior product. Discussion of the problems of shrinkage and distortion and their solution follows, together with an analysis of the metallurgical aspects of appropriate heat treatment, including sealing losses. Examples of repair welding are given.

Paul Ffield

A few years back every repair weld on a casting placed a stigma on that casting and left the impression that an inferior article was being substituted. This condition was still further aggravated because marine engineers were progressing towards higher temperatures and pressures and consequently had to demand greater integrity from the component parts making up turbines and other high pressure steam units. Welding had not really come into its own and was usually considered by engineers to constitute a discontinuity in the piece welded very much as though the deposited material were merely a plug. Admittedly, many of the welds made in castings at that time were not a credit to the welding art and there are reputedly cases on record of welds "falling out of the casting".

Several changes were brought about which materially altered the welding of castings. Coated electrodes were developed, and specialized techniques of welding heavy castings were introduced. It was soon realized that to weld a heavy casting, while it was cold, irrespective of its analysis, was inviting trouble. Cracks and spalling were likely to occur even though the same steel in lighter sections was considered readily weldable. The importance of preheating and stress relieving and the judicious processing of the deposition of weld metal was becoming more thoroughly understood. The inevitable result of all these developments was the production of sound welds, superior to the casting which was being welded.

The developments in welding altered the light in which welding was regarded by marine engineers. It was realized that a sound structure consisting of a welded casting was preferable to an unwelded casting which might contain hidden defects. The Navy Department brought the question of sound cast structures to a point much nearer reality when they pioneered the use of radium for inspection of castings. The outstanding work of Briggs and Gezelius is too well known to require any further comment.

The Bureau of Engineering assumed leadership with the foundries and shipbuilders in a concerted drive to produce better cast structures. Within liberal limits the Bureau of Engineering would permit the welding of many castings provided the repair was subsequently stress relieved and radiographed. The rejections of castings became fewer and fewer and without a doubt sounder castings were being obtained Outright rejection of high pressure castings at Fore River has amounted to less than 4 per cent in the last two years. It is believed that this experience is typical of other building yards.

The liberal attitude of the Bureau of Engineering towards welding soon produced such developments as cast structures especially designed for welding. At Fore River, were developed such castings as the high pressure turbine casing shown in Fig 1. This casting is built up of three separate castings welded into a single unit The advantages for such a structure are numerous. However, the most desirable feature of this type of design is that it enables the foundryman to position each section in the most advantageous manner for making the casting. Sounder castings must result from such technique It might be noted in passing, that the reduced price obtained from the foundry, because the casting was subdivided, slightly more than offset the cost of welding.

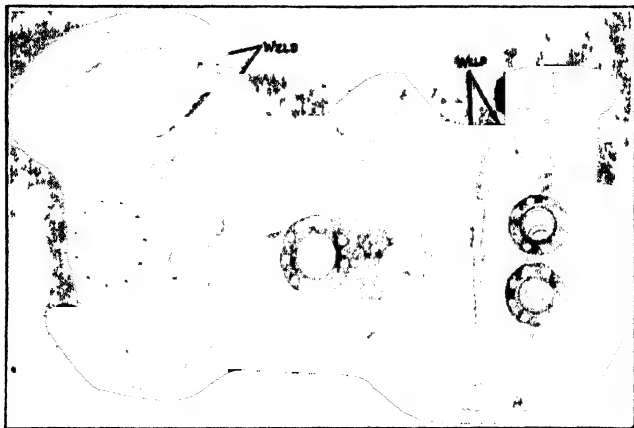



Fig. 1. Turbine casing composed of 3 castings welded together.

The welding of such structures as the built up turbine casings afforded the Bethlehem Steel Company considerable welding experience and necessitated a certain amount of research concerning control and prediction of welding shrinkage. This experience seems to indicate that welding must cause distortion; that this distortion can be controlled and even offset, and finally that we have no cases on record of stress relieving causing distortion provided the work is reasonably supported and properly heated. This information has since formed the basis for still further developments in the welding of castings.

Even in the best regulated shops a defect will sometimes be revealed when the final machine cut is being taken on a casting. In the authors' opinion rarely are halfway measures applicable to such a condition. The defect must be excavated, repaired by welding, and the whole casting re-stress relieved.

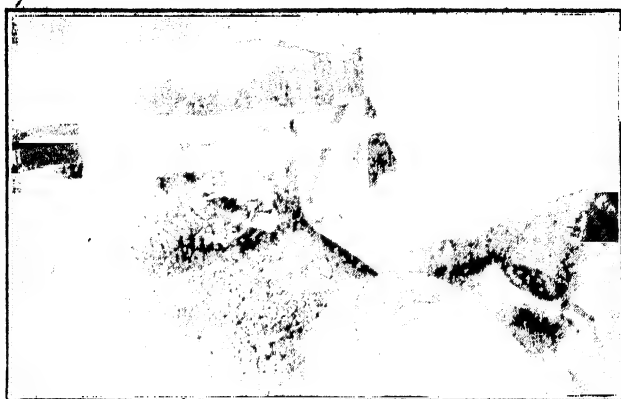



Fig. 2. Steam inlet and turbine casing after partial removal of defects.

Halfway measures such as seal welding the defect are hazardous. Furthermore, we now have strong indications that at the present operating temperatures the buried defect may creep through the seal weld, producing a leak. Repair by seal welding is then out of the question.

When such a condition arises the engineer must first determine whether the defect is serious. This can usually be determined only by radiography. It might be well to point out here that the Navy's radiographic standards should not be considered as the sole means for judging the seriousness of such a defect. These standards were developed primarily as a general guide and some of the acceptable conditions "no repairs required" may not be acceptable if in a location of maximum temperature and pressure or at points of stress concentration.

Before citing several examples of finished castings which have been repaired, it might be well to clear up some of the controversial points concerning the hazards of such a process. Distortion of repair-welded castings is the result of movement caused by stresses which have been introduced during the course of the repair. The two sources of stress are shrinkage of the filler metal, and differential expansion arising from temperature gradients set up during the various phases of the welding process. Stresses originating from shrinkage of the weld metal are negligible in comparison to the stresses resulting from temperature differential. The magnitude and ultimate effect of thermal stresses are dependent principally upon such factors as preheating, quantity and rate of deposition of weld metal, location of the weld with respect to the casting, and method of subsequent stress relief.

Simple calculations show that the intensity of thermal stresses per degree of temperature difference is equal to (modulus of elasticity) $\times$ (coefficient of thermal expansion). On this basis, for C-Mo steel the stress intensity per degree F of temperature differential (at 400 degrees = (30×10^6) (7.9×10^{-6}) = 237 pounds per square inch. Thus, with a temperature differential of 150 degrees F., a stress of 35,000 pounds per square inch is raised, a value approaching the yield point of the material.. Since the welding procedure involves the application of heat, it is necessary to consider each step in this welding in relation to establishment of temperature gradients.

The principal metallurgical reason for preheating a casting prior to welding is to prevent hardening and embrittlement of the weld area. But preheating serves not only to prevent embrittlement, but also to minimize the sharp

temperature differential immediately established by deposition of liquid metal. The minimum preheating temperature depends upon the composition of the material and the amount of metal to be deposited. With C-Mo steel a minimum temperature of 400 degrees F. is used even when small amounts of repair are to be made. When large amounts of metal are to be deposited, a higher preheating temperature is used in order to allow for heat lost by radiation.

During welding, the weld zone acquires a temperature far in excess of the casting itself, and thus the thermal expansion of this zone varies from points removed from the zone. On cooling, the weld zone cools at a faster rate and has a greater temperature range through which it must cool. All points do not cool through the same temperature range at the same time. It is through this variation in thermal expansion and contraction that internal stresses of high magnitude are set up. When they exceed the yield point, the material upsets upon itself, which leads to distortion if movement is unrestricted. The intensity of stress is especially high if variation in section exists in this area.

Location of the weld is also a factor in determining ultimate distortion. In a zone where movements become entirely localized, total distortion will be small. But if the zone is located in a position where small local movements become magnified into larger movements at a remote point by mechanical action, then the total distortion will be appreciable.

Although the process of stress establishment is inherent in the welding process, certain measures can be taken to minimize its magnitude and effect. Among these are control of welding rate, and judicious peening. Since distortion results directly from upsetting of the metal adjacent the welding zone, peening of each bead and the immediate surrounding area counteracts this upsetting. In addition, the weld area can be peened sufficiently to upset the metal in the opposite direction by an amount equivalent to the greater contraction which this area would normally undergo on cooling. Some care must be exercised in peening, however, since the casting has locked-up stresses which might easily lead to cracking. As will be explained later, peening may also be used in certain instances to correct distortion in required castings..

Another factor creating thermal stresses is quantity and rate of welding.

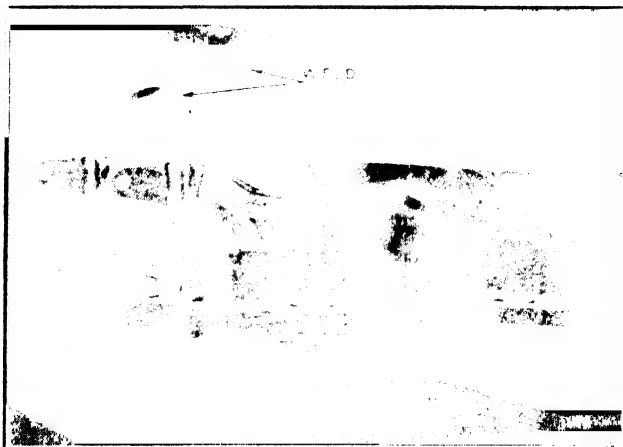



Fig. 3. Repair-welded turbine casing after stress relieving.

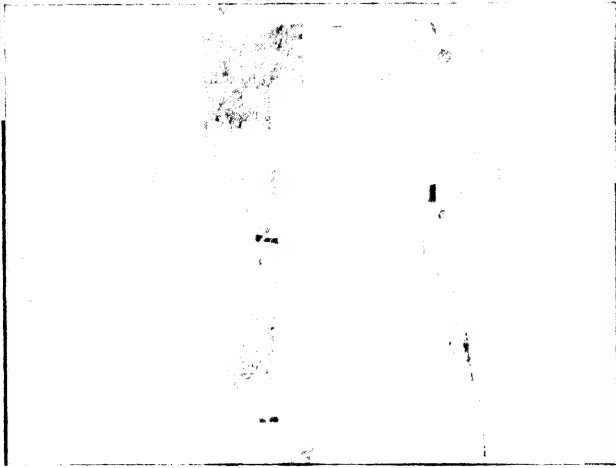



Fig. 4. Rough-bored casing after removal of defects.

Ideally, a minimum of distortion would result if the entire volume of weld metal could be deposited at once, or conversely, if the filler metal could be deposited in infinitesimally small amounts. Deposition of the entire quantity at once would create an appreciable thremal stress, but the condition of stress would last for only a comparatively short time. By depositing a very small quantity of metal at a time, the temperature gradient is held to a minimum. It is by the use of intermediate welding rates that maximum distortion results, because a sizable thermal stress is established and allowed to act for a period of time, thus causing movement and distortion in a manner similar to creep. In practice, the nearest approach to ideal conditions is obtained by employing a very small rate of feed. For example, less distortion is encountered by using a 1/8-inch wire, than with 5/32-inch or larger. By a combination of this lower welding rate and judicious peening, distortion can be held to a minimum.

Stresses locked up during welding are mostly dissipated during the stress-relieving operation. At a temperature of 1100 degrees-1200 degrees F. atomic readjustment and resultant neutralization of stresses occurs without distortion when certain precautions are observed. The principal precautions are proper support of work and maintenance of slow heating and cooling rates, with periodic soaks. For even in the stress-relieving operation new thermal stresses can result from non-uniform heating and cooling.

It is generally agreed that 400 degrees F. per hour divided by the maximum thickness in inches is a conservative heating rate, but there is an added factor of safety in employing one half of this rate and this is recommended in important work. Unlike other heat treating operations the period of hold at temperature is not a linear function of thickness. Two hours at temperature is sufficient, for during the first hour the stresses of high intensity are reduced to those of the initially lower value, and after two hours all are reduced to a safe level. The work should not be removed from the furnace on the way down until a temperature of 400 degrees F. is reached, in order to avoid new thermal stresses.

The next point frequently raised is that oxidation or scaling is a factor to be considered. In a gas-fired furnace the losses of actual steel from scaling

at the usual stress-relieving temperature have been negligible. Nothing other than a fine red powder has ever been observed. Even in electric furnaces operated without atmospheric control the amount of oxidation at 1200 degrees F. is not excessive. Cleaning by kerosene or other measures removes the loose oxide and presents a surface equal to the surface of any turbine which has been run for some time. It is believed that the word "scaling" is responsible for most of the apprehensions from this source. Table I shows typical losses obtained from scaling in carbon-molybdenum and carbon steel castings at the upper limit of the stress-relieving temperatures.

As a result of the fears of loss of metal from scaling, it has sometimes been proposed that on finished machined sections it is advisable to stress-relieve at a lower temperature for a longer period of time. In the authors' opinion such a precaution is unnecessary and furthermore, is liable to lead to improper stress-relieving. Stress-relieving may almost be considered a short time creep treatment with certain fibres flowing plastically. Time and temperature are the conditions to be considered. What the relation between time

Table I—Loss in Thickness of Steel Due to Scaling in an Electric Furnace at Stress Relieving Temperatures

Time at 1250 degrees F.	Average Reduction in Diam. Mild Steel Inches	Average Reduction in Diam. C. Mo. Steel Inches
1 hr.	0	.001
2 hrs.	0	.001
4 hrs.	.001	.001
8 hrs.	.001	.001
16 hrs.	.001	.001
24 hrs.	.002	.002

Note: These losses are measured on the diameter of a ¾" rd. bar. Losses on a plane surface would be one-half of the above amounts.

and temperature is has not yet been determined as far as the authors know. 1200 degrees F. for one hour may be entirely adequate for a carbon-molybdenum steel. However, at 900 degrees F., 5-hours or 5000-hours may not be sufficient. Until research has shown what the relationship is between

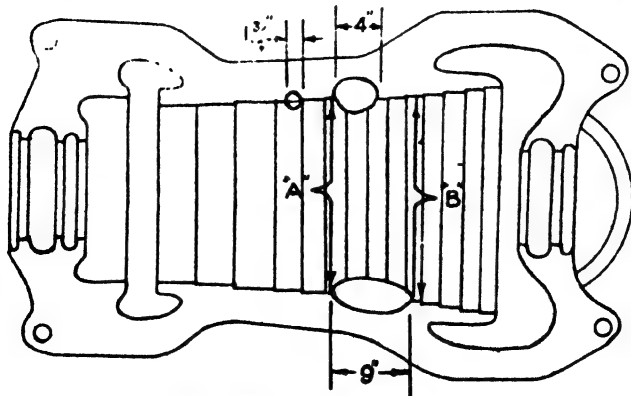



Fig. 5. Distortion due to welding. Before welding, "A" 21.986-inches, "B" 23.003-inches. After welding "A" 21.997-inches, "B" 23.020-inches. After annealing "A" 21.989-inches, "B" 23.015-inches. Welding caused a concave deformation at the horizontal joint of .007-inch.

time and temperature for stress-relieving, the authors would not suggest lower temperatures and longer times.

In regard to actual repair of defective castings, the following paragraphs describe procedures used on three groups of castings. With the first group of castings, a certain amount of distortion could be tolerated, and no special precautions to avoid distortion were therefore required. The second group represents castings where re-machining could be used to correct a limited amount of distortion. The third group is representative of finish machined castings where no machining could be permitted after repair welding. Weld distortion with this group, therefore, had to be minimized and subsequently eliminated by means other than machining.

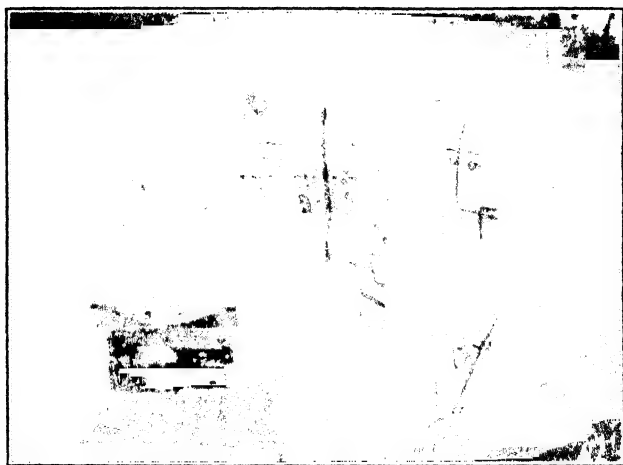



Fig. 6. Partial removal of defects in turbine casing.

With respect to the first group of castings where a small amount of distortion can be tolerated, Fig. 2 shows the high pressure steam inlet of a high pressure turbine where radiographic examination disclosed a defect, shown in the photograph after excavation. Since this location is in the region of maximum temperature, and since the stresses on the neck of the inlet pipe are usually rather indeterminate due to effect of connected steam lines, a complete excavation of the defective area and a sound weld were necessary. In this case minor distortion could easily be accommodated even if it meant refacing the inlet flange. Special precautions for this repair therefore, were not necessary. The casting was positioned for downhand welding and preheated over a generous area to 400 degrees F. The welding was deposited in and around the sides of the cavity, rather than uniformly filling the cavity. Each layer was peened partially to offset the welding shrinkage and to insure slag removal. Measurements were taken between the flanges of the inlet and the flanged joint of the casing before, during, and after welding. After welding, the casting was stress-relieved at 1250 degrees F. It was not necessary to use an elaborate jig to support the casting. It was placed on a car bottom furnace and supported at various points with steel wedges as shown in Fig. 3. After stress-relieving, measurements showed that the casting had distorted less than .001-inch at any point. There was slight tarnishing of the machined surfaces and the paint on the casting was burned off, otherwise there had been no ill effects. The casting, however, was now

definitely sound and no trouble from a hidden defect in this region would occur.

Fig. 4 represents the second group of castings where distorted areas can be re-machined after repair. When the final cut was being taken on the flanges of this turbine casing, two cracks were disclosed which were not visible when the casting was rough machined. The casting had been rough but not finished bored. The bore was still 1/16-inch oversize, so warpage could be permitted which was within this limit. It would also be a simple matter to take a light cut off the flanges.

After cleaning out the cavities, weld metal was deposited approximately in the same manner as in the previous casting, and the usual precautions of preheating and cleaning were followed. The welding caused a convex deformation of the horizontal joint of approximately .007-inch. The bore of the casting also tended to widen, by approximately .012-inch. It can be noted by referring to Fig. 5 that a slight recovery was obtained in the "B" reading in the bore after stress relieving this casting. After completion of the repair, the horizontal joint was re-machined to eliminate the concavity of .007-inch, and the casting was then finish-bored.

Another example of repair welding, where a small amount of distortion can be corrected by re-machining, is represented by a horsepower turbine casing shown in Fig. 6. In this casting defects were present in the wall

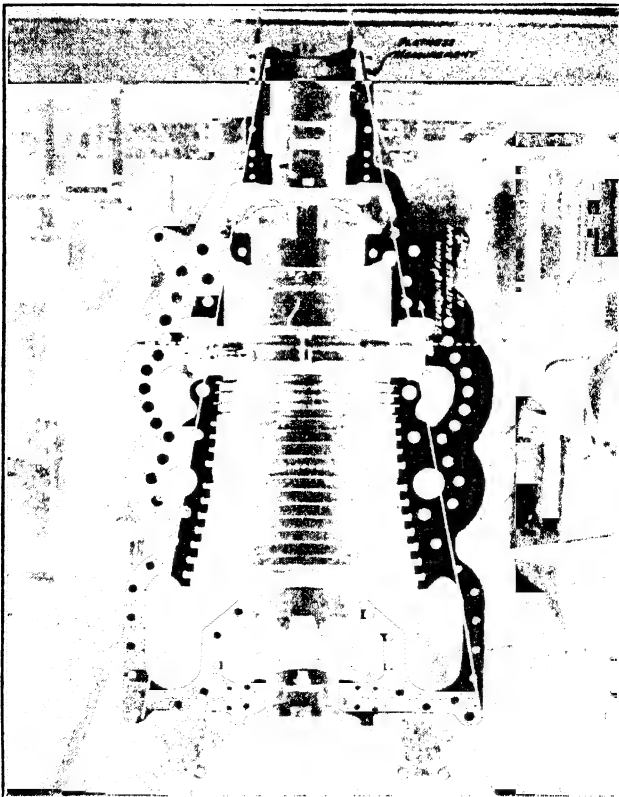



Fig. 7. Partial removal of defects in turbine casing.

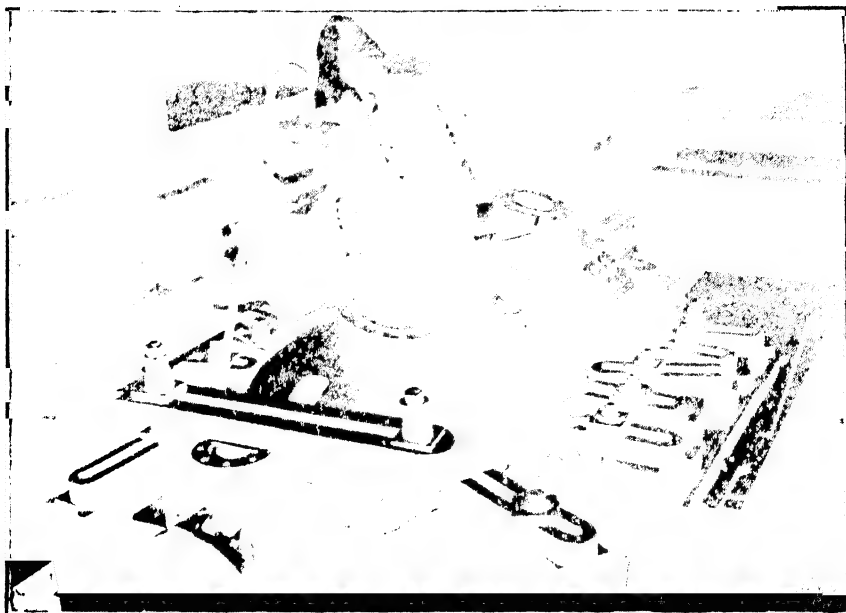



Fig. 8. Method of restoring distorted turbine casing to required flatness.

midway at the third staging, and also in the walls of steam chest. After removal of defects, welding was performed on the preheated casting. Each layer of weld-metal and adjacent area was peened, and a total of thirty pounds of weld metal was deposited. The casting was stress relieved at 1200 degrees F. for two hours. Measurements after welding showed a high spot of .006-inch on one flange. A grinding operation restored required flatness to the casting.

An example of repair where no machining is permissible after welding is represented by an I. P. turbine casing shown in Fig. 7. It can be noted that four rows of blading are in place. Distortion therefore had to be minimized during welding and then eliminated by means other than machining. Defects in this casting were located within the "T" slot in the way of impulse blading. The defects were so extensive that removal consisted essentially of cutting the casting in two except for the flanges. Fig. 7 shows some of the excavation under way. This was continued along the slot shown. Prior to welding, measurements were made as indicated in Fig. 7, for convenience called "flatness" measurement and "C" measurement.

The casting was preheated to 400 degrees F. for welding. Peening of each layer of weld metal and surrounding area was practiced as previously described. Approximately fifty pounds of weld metal were deposited. After stress relief at 1050 degrees F. for four hours, measurements showed loss of flatness of .014-inch in a length of seven feet, and a contraction of .005-inch across the "T" slot. It can be seen from the photograph that the contraction across the slot is the action which caused loss of flatness in the flange. In this casting, the width or diameter of the bore did not change beyond the small permitted tolerance.

Distortion was corrected in a manner shown by Fig. 8. The casing was supported on blocks, and the small end of the casing was loaded so that

the metal behind the "T" slot was put in tension. Peening of this area, as shown in the photograph, caused the metal to spread in a direction with the applied tension, which was opposite to original weld shrinkage. Peening was continued until measurements showed that distortion was eliminated. The stress relief treatment given this casting did not cause any dimensional return, but in other cases it has been found necessary to straighten beyond the point finally desired, thereby allowing opportunity for slight dimensional return in stress relieving.

In summary, it has been shown that castings with large areas of finish machined surfaces, whose flatness and dimensions are required to be maintained within close limits, can be successfully repair welded. Castings up to seven feet in length and weighing two tons have been repaired with as much as fifty pounds of weld metal added. Although problems connected with repairs have differed somewhat with each particular casting, observance of precautions previously described and use of approved welding technique have made it possible to repair successfully castings which in former years would have required rejection.

Actual cost savings which may be attributed to these methods of repair cannot be evaluated. The saving for any one casting would of course be the cost of all handling, laying-out, and machining which had been expended on the casting prior to discovery of the defects, less the cost of the repair by welding. These factors will vary from one casting to another. Another factor which must be considered even more than monetary saving, especially since Pearl Harbor, is the saving in time which may result from the repair. Outright rejections of machinery castings must be held to a minimum if the orderly progress of ship construction is to be maintained. From the standpoint of safety, a casting which has been radiographed and repaired by welding is considered much more dependable than a casting which has not been radiographed. This is an important consideration when the castings involved carry high temperature, high pressure steam, for a sound casting presents less danger to the operating personnel. A casting which has been repaired during manufacture also means that less operating time will be lost because of necessary repairs after the ship has been in service for some time, since an internal defect will sometimes pass hydrostatic and other routine tests only to work its way to the surface of the casting under operating stresses.

The authors wish to acknowledge the co-operation of Mr. J. E. Burkhardt, Technical Manager, Bethlehem Steel Co., Shipbuilding Division, whose advice and constructive criticism has been most helpful. Most of the development work on castings built up by welding has been due to his insistence on obtaining sound castings whether it be by design, by radiography, or by repair. The authors also wish to acknowledge the helpful co-operation of Rear-Admiral P. B. Dungan, formerly Inspector of Machinery at Fore River; Captain R. W. Paine, Engineering Superintendent, Boston Navy Yard; and Commander C. O. Kell, Production Manager, Boston Navy Yard whose advice concerning repairs of steel castings has been most helpful.

Chapter VIII—Welded Revolving Cranes

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Subject Matter: While various improvements were made from time to time in design and construction of revolving cranes, probably no other procedure in the work of the company has enjoyed so much success as that of modern arc welding. In the case of the sample crane described, the saving in material was 12 per cent and in labor 22 per cent. At this rate, the saving in the company's business would be $100,000 per year, and if it resulted with all the revolving cranes built in the entire industry, the annual saving could be nearly one million dollars. The decrease in weight and increase in rigidity increase the service life of the equipment.

The full-revolving, whirler-type crane has become the basic erection tool of the American shipbuilding industry. Having the advantage of extreme flexibility over stationary cranes, the traveling gantry type, illustrated in Fig. 1, has become the most popular for shipbuilding, drydock and general construction work.

It is well recognized that the advance of welding in ship construction has resulted in the prefabrication of larger and larger assemblies. This condition, and the installation of heavier equipment and machinery, has

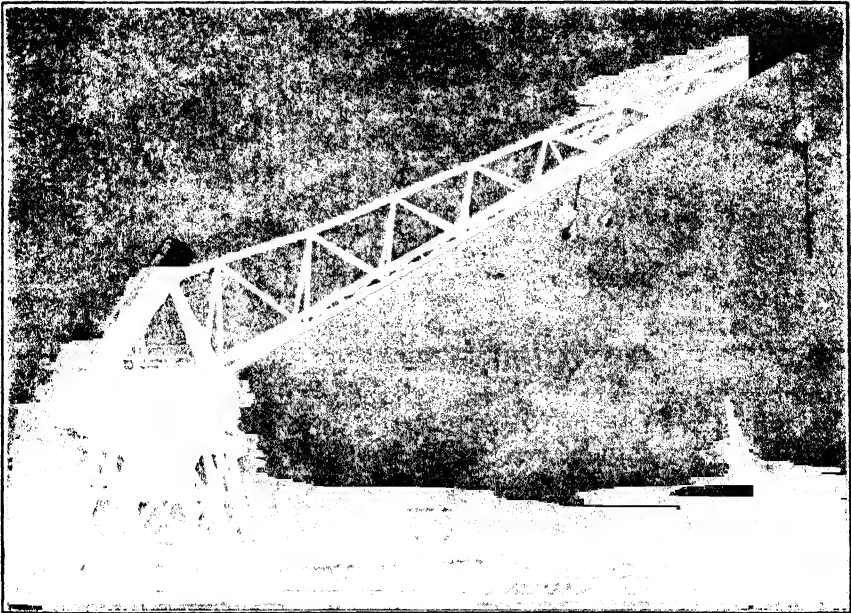



Fig. 1. General arrangement of 25-ton screw-luffing crane.

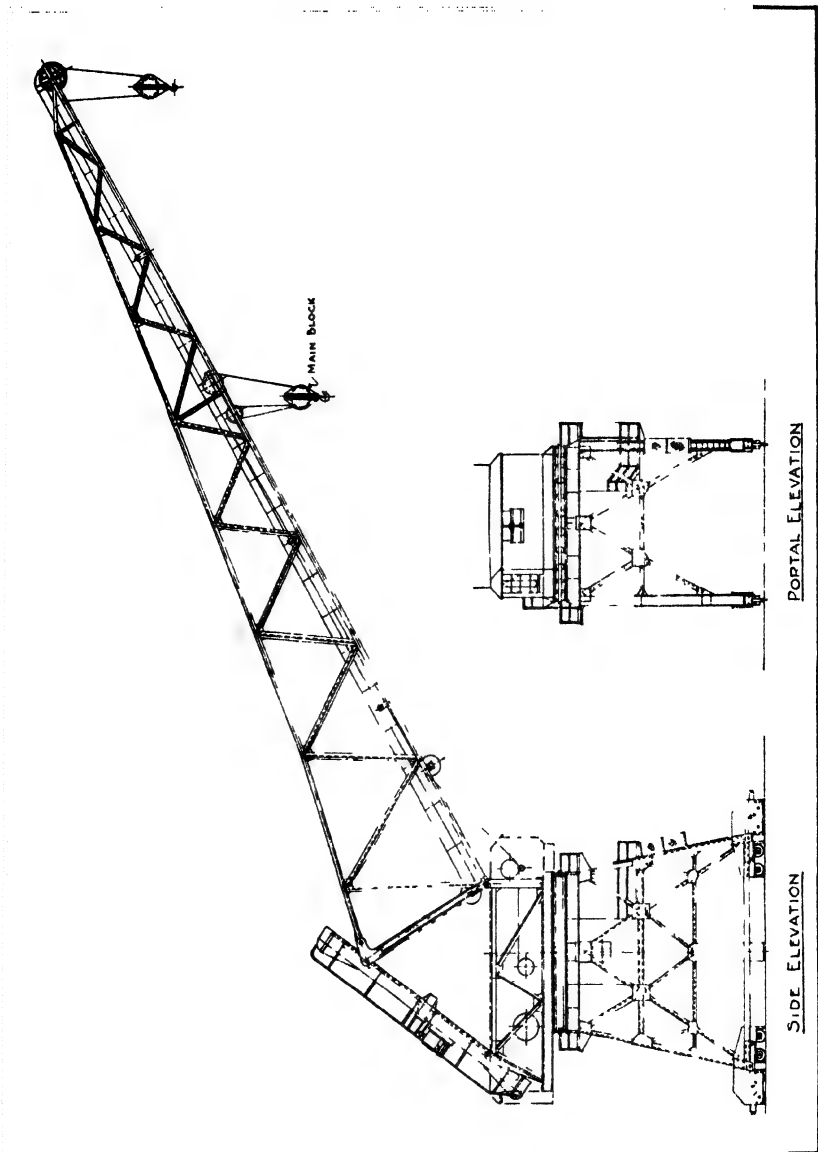



Fig. 2. Side of portal elevation.

prescribed heavier crane capacities for handling these units. At the same time, utmost in safety must be incorporated as in all cases a failure would result in serious financial loss, serious hazard to nearby workmen and a serious retardation of our strained defense program. Complying with both of these trends, the all-welded, screw-luffing crane described in this paper was developed.

The general arrangement of the crane is shown in Fig. 2. Mounted on a 35-foot high gantry with runway rails spaced at 25-foot centers, it is equipped with a 150-foot triangular shaped boom of the screw-luffing type providing maximum flexibility and safety for heavy-duty shipyard

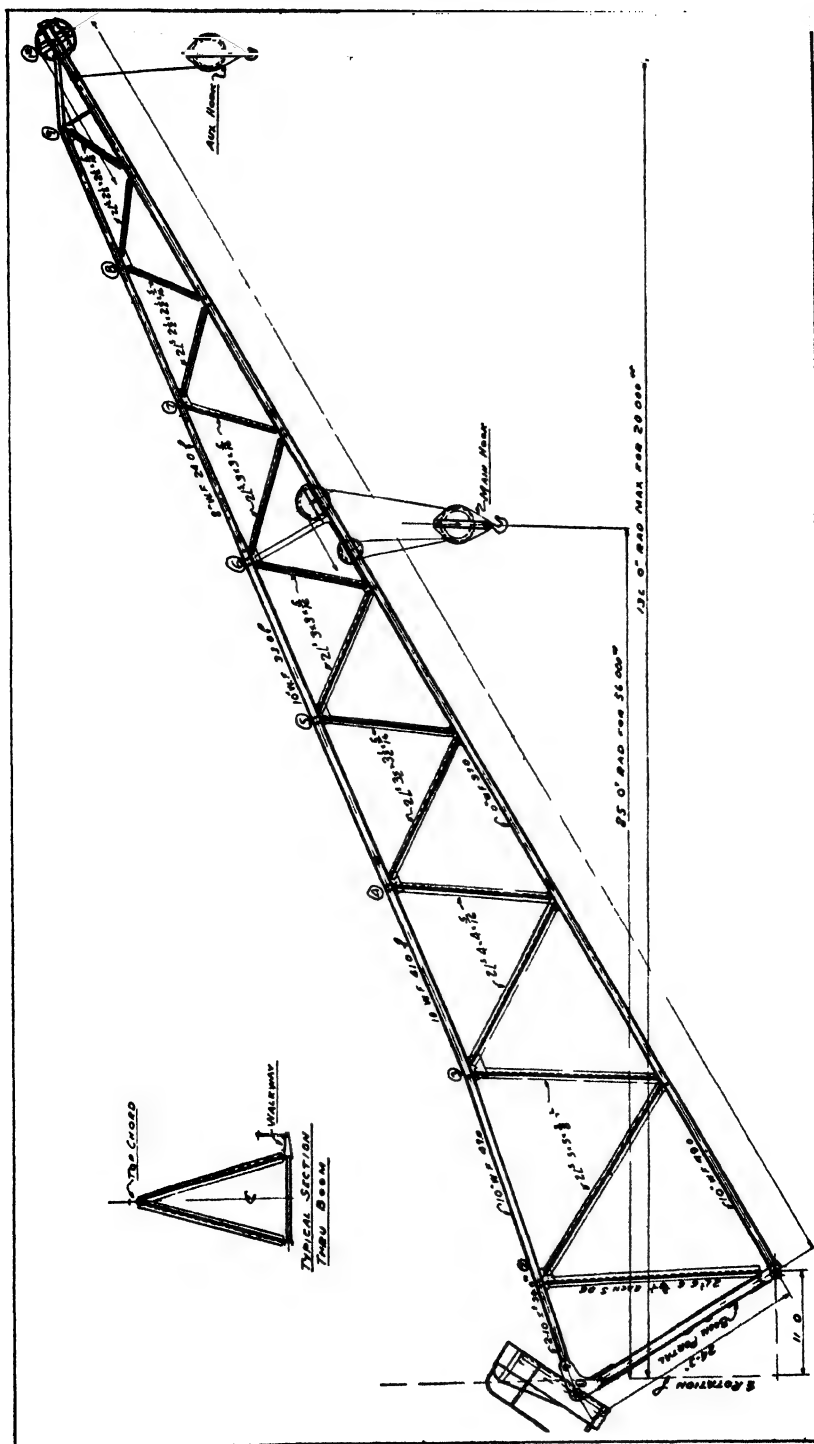



Fig. 3. General arrangement of boom.

service The crane has a rated capacity of 25 gross tons or 56,000-pounds at a radius of 85-feet and 33,000 pounds at a radius of 98-feet for the main hoist hook An auxiliary hoist provides a capacity of 20,000-pounds at a 156-foot radius

Boom—The boom is pin connected to the top of the front portal of the longitudinal trusses Its triangular shape and framing details are departures from orthodox boom design, and the efficient proportion of the component parts was made possible through modern welding design and practice.

The general arrangement of the boom is shown in Fig 3, indicating the makeup of its various members These are proportioned to resist a combination of dead load plus live load, plus 25 per cent impact on live load, plus side forces due to slewing or seven pound side wind The resultant stresses are obviously compression in the bottom chord, reaching a maximum magnitude of 240 kips for each of the two bottom chord members adjacent to the boom foot Similarly, the top chord tension at the screw frame connection totals 340 kips The resultant web stresses, however, are relatively small, and these parts are proportioned largely to satisfy their l/r requirements Accordingly, the only main member material that can be substantially reduced through welding is that of the top chord, which, by maintaining gross section, can be reduced by approximately 15 per cent over riveted construction It is in the design of the details and connections, however, that welding helps to materially reduce the weight of this very important part of the crane For every pound of weight reduction on the boom, the load on the remaining structure is reduced by ap-

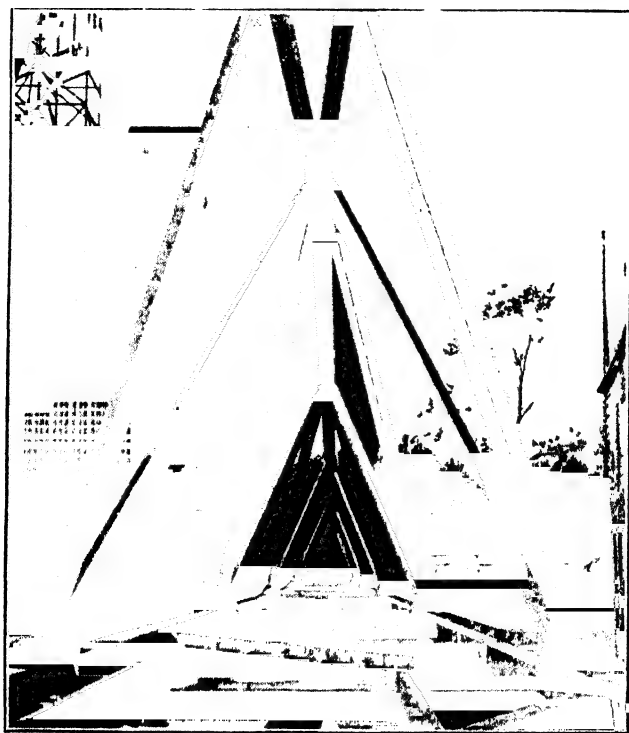



Fig. 4. Welded design made triangular boom practical.

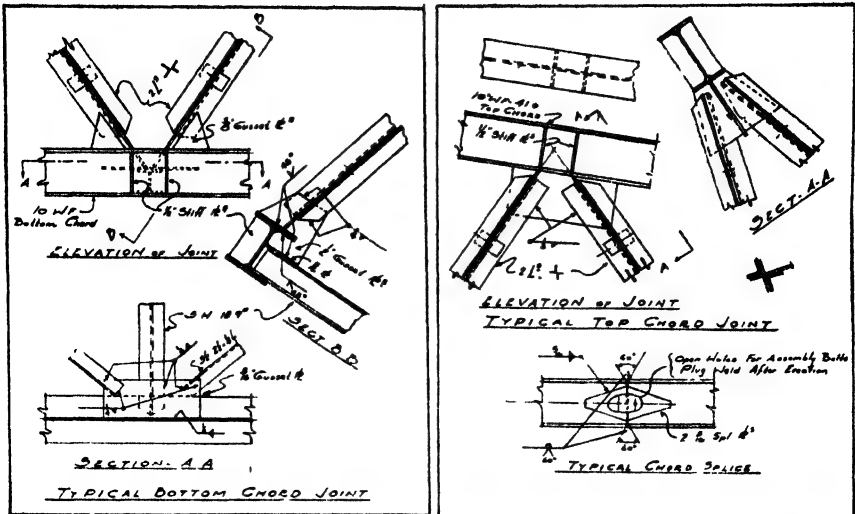



Fig. 5. (left). Boom details, typical bottom chord joint. Fig. 6. (right). Boom details, typical top chord joint, (above), and typical top chord splice, (bottom).

proximately five pounds. In order to further reduce the weight of the boom, the chord members were built of copper-nickel alloy steel, permitting an increase in allowable unit stresses of one-third over that of ordinary carbon steel. Accordingly, a welding electrode possessing similar properties to those of the parent metal was selected, after having tested numerous specimens under various unusual and severe conditions.

As mentioned previously, the web members must be proportioned to meet maximum l/r requirements. For this purpose two angles arranged to form a star-shaped strut were selected, making a very efficient compression section. Plate battens, welded to the outstanding legs of the angles and alternating by 90 degrees, provided an economical method of fabricating these sections.

The arrangement of the primary members to form the triangular shape of the boom is illustrated in detail in Fig. 4. Gussets were arranged normal to the webs of the chord members, and placed in the same plane of the

Fig. 7. Typical splices and connections at boom top chord.

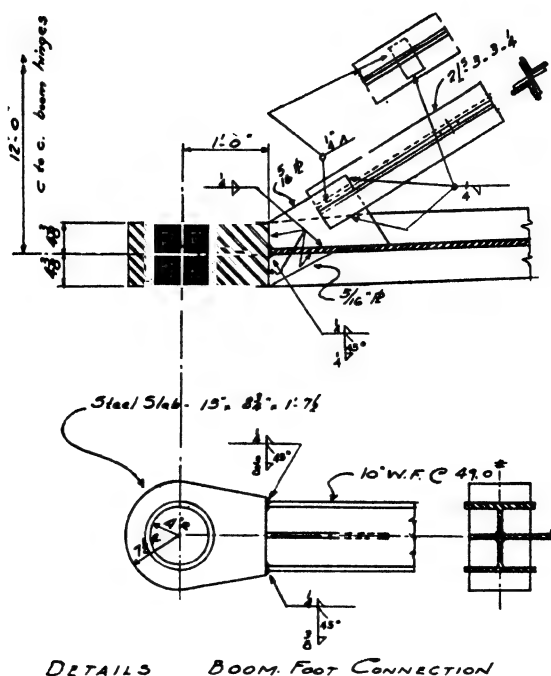



Fig. 8. Details of boom-foot connection.

sloping diagonals, thus greatly simplifying the connections of chords to diagonals.

Details of a typical bottom chord joint are shown in Fig. 5. In addition to the primary gusset plates mentioned above, small triangular gussets attach the outstanding legs of the diagonal members to the chords, thus relieving the primary gussets from any possible lateral stresses. The bottom chord lateral system is designed to transmit all lateral loads due to slewing or side wind to the main framing of the rotating structure. As indicated, horizontal struts composed of 5-inch H sections are framed into the bottom chord, while single angle diagonal cross bracing is connected to strut and chord through a common gusset plate. Vertical stiffener plates "back-up" the top flange of the chord member opposite the primary gusset connection. To develop this joint with riveted connections would require at least three times as much detail material.

A similar detail showing a typical top chord joint is indicated in Fig. 6. A common vertical gusset assists in transmitting the diagonal stress from each of the four primary gussets to the chord member. The remaining details are similar to the bottom chord joint previously described.

Also illustrated in Fig. 6 is a typical chord splice. The flanges of the member were butt welded, while the web was developed through two side splice plates as indicated. These splice plates were provided with erection holes, thus simplifying the erection of adjacent boom sections.

The photograph, Fig. 7, shows a typical top chord splice as well as a typical joint arrangement both of which have been described above.

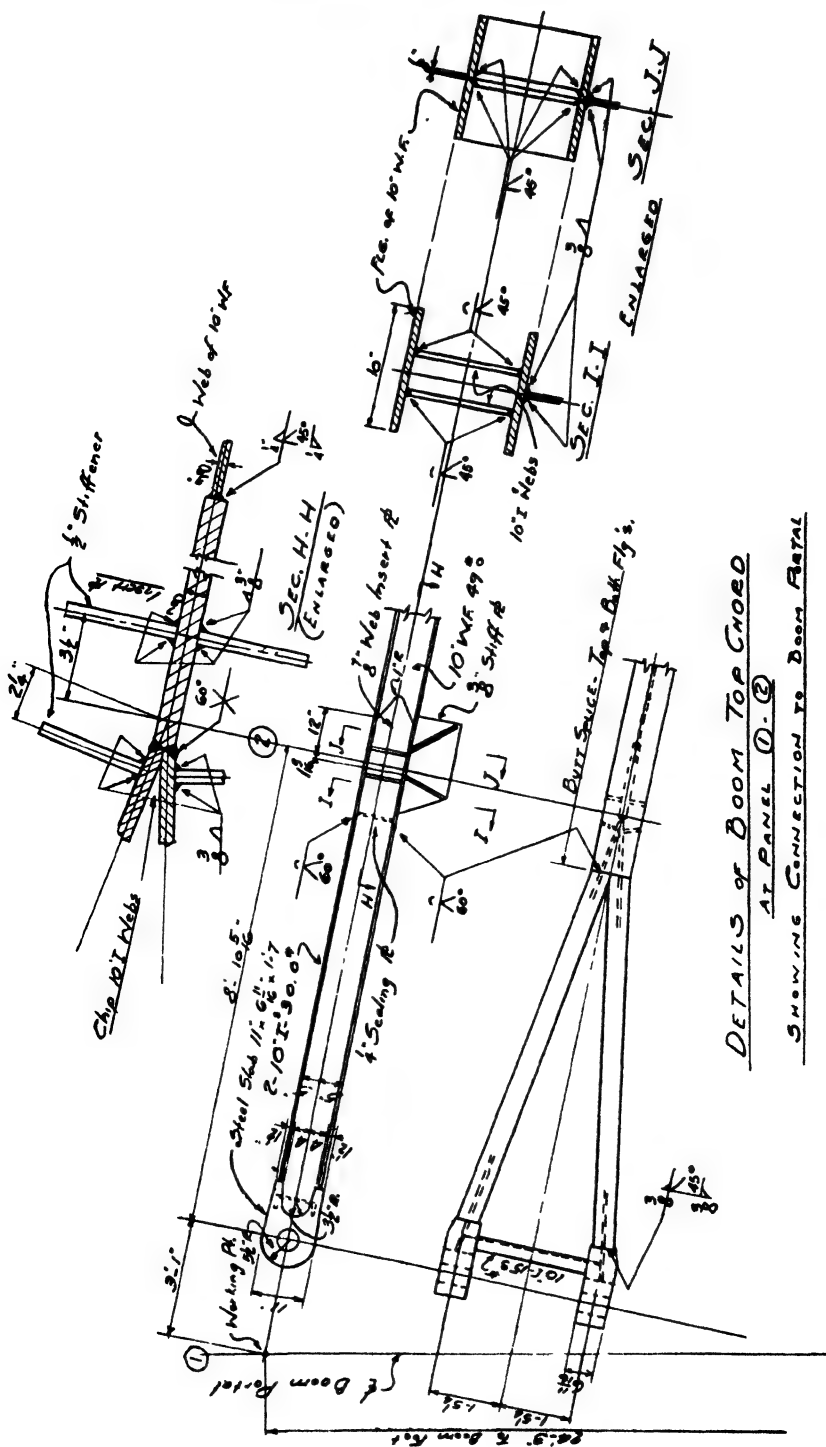



Fig. 9. Details of boom top chord.

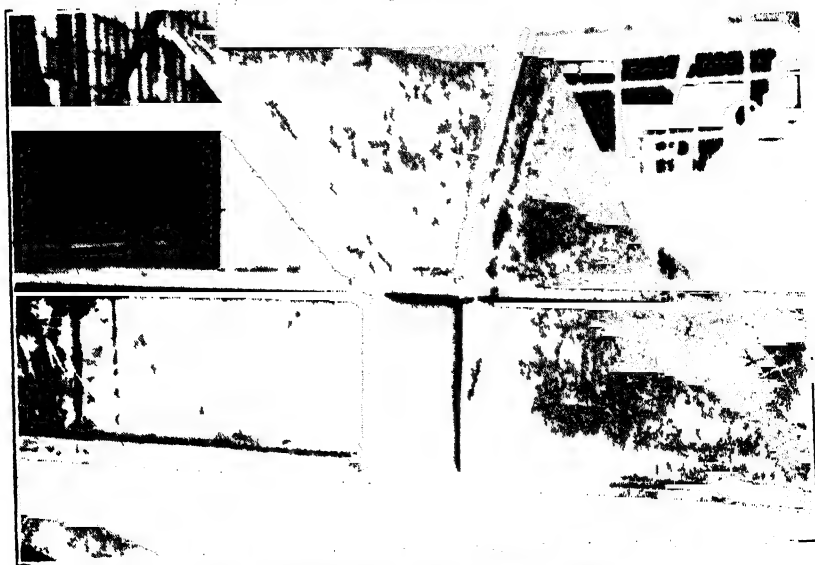



Fig. 10. Details of top chord transition splices

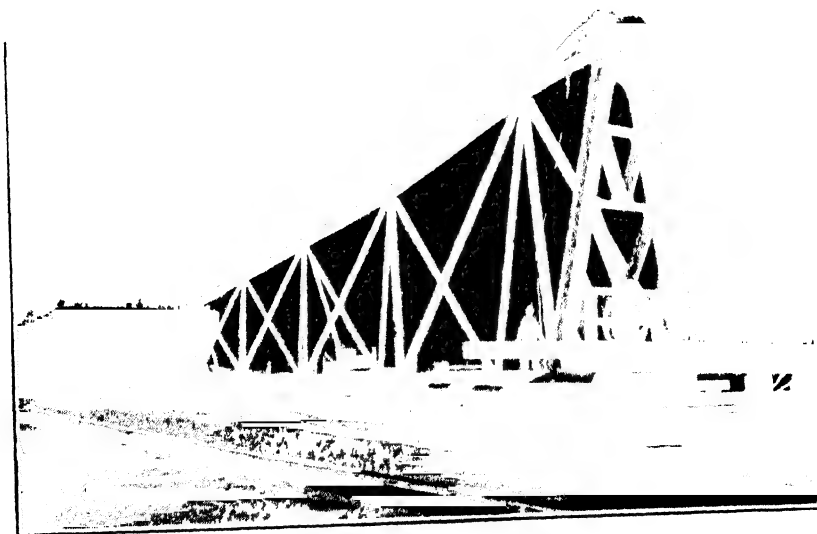



Fig. 11.—Pre-assembly of 100-foot boom.

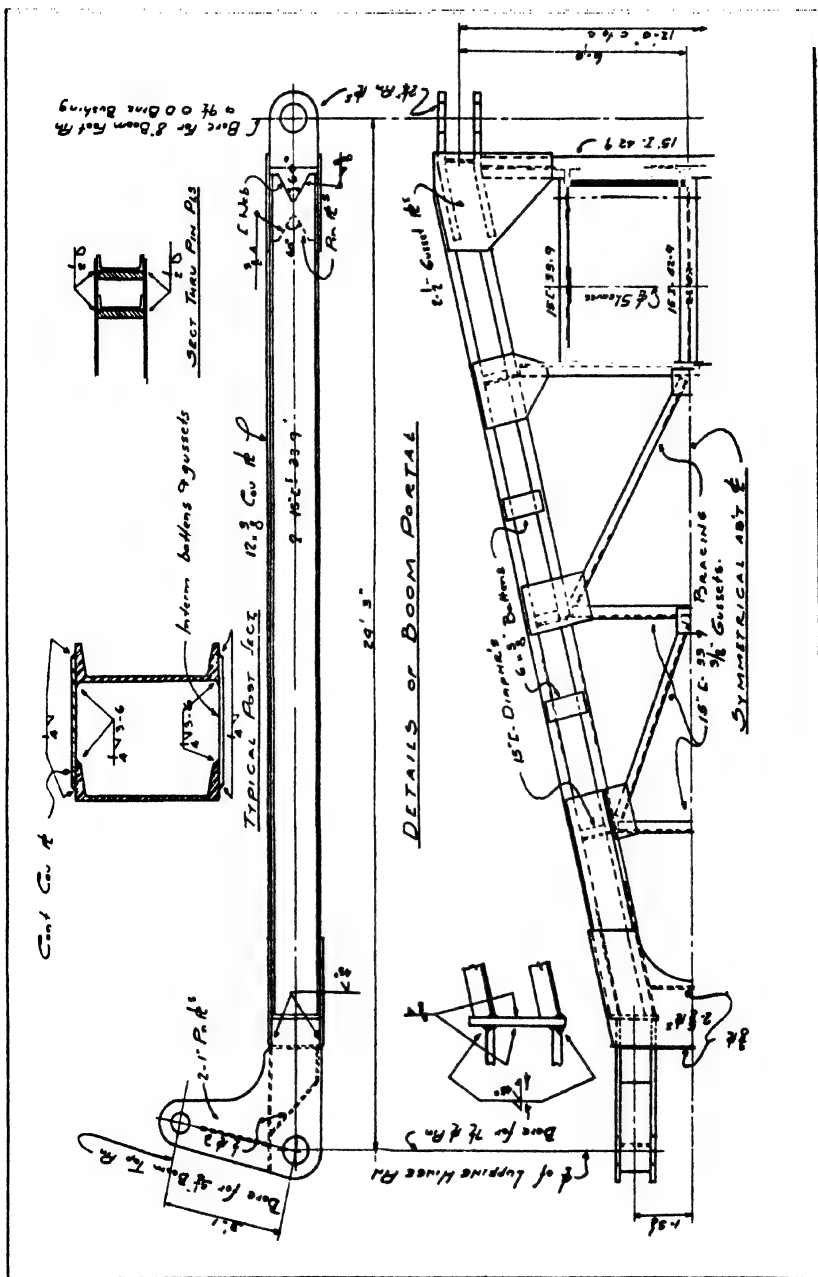



Fig. 12. Details of boom-portal.

Details of the boom foot connection are shown in Fig. 8. Designed to transmit a compression load of 240 kips, the flanges and web of the bottom chord beam are butt welded to a steel billet. In addition to the 45 degrees Vee weld to accommodate the stress flow from the relative thin sections of the rolled shape to the solid billet, the boom foot billet is bored for a bronze bushing to receive the lower hinge pin. As indicated, the bottom chord laterals are connected to billet and chord by means of a gusset plate. The resulting joint is simple and neat in appearance, yet highly efficient.

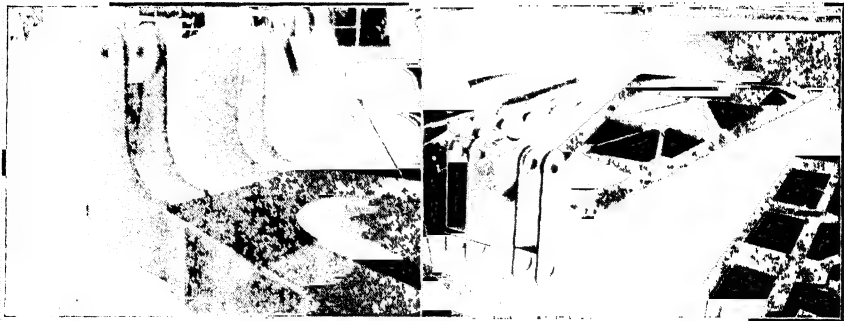



Fig. 13, (left). Top connection boom portal. Fig. 14, (right). Boom portal ready for shipment.

A most interesting detail is the top chord splice illustrated in Fig. 9, the function of which is to transmit a tension stress of 300,000-pounds from a single 10-inch wide flanged beam to two 10-inch standard I beams. Since the combined area of the two webs of the standard I beams was considerably larger than that of the single wide flange beam, a 7/8-inch web plate was inserted to transmit the stress from the pair of I beams to the web and flanges of the single beam. The transition was completed by butt welding the flanges of the three primary members involved. Stiffener plates were provided to back up the diagonal gusset plates, and a sealing plate was inserted between the webs of the two I beams to prevent water from lying in the Vee shaped pocket formed by the junction of the two members. The details of this joint are further illustrated in Fig. 10, which shows the connection as it actually looks in position on the boom.

Also shown in Fig. 9 is the hinged joint of the top chord where it connects to the boom portal. Each of the two 10-inch I's was welded to a steel billet as indicated. Again, the flanges of the chord members were Vee butt welded to the billet with additional fillet weld reinforcements on each side to assist proper stress transition.

The assembled boom is illustrated in Fig. 11. Convenient erection holes were provided for the various shipping units to insure accuracy and alignment and to expedite the final field assembly.

Boom Portal—The boom stresses are transmitted to the basic rotating structure through the luffing screw and boom portal. These two highly stressed and important members are hinged to the longitudinal platform trusses at their lower ends and converge at their upper ends to form an apex of a large triangle to which point the boom top-chord is attached. The front leg of this triangle, identified as the boom portal, is detailed in Fig. 12.

As indicated, the two main post sections of the boom portal consist of a pair of channels and a continuous cover plate forming an open box

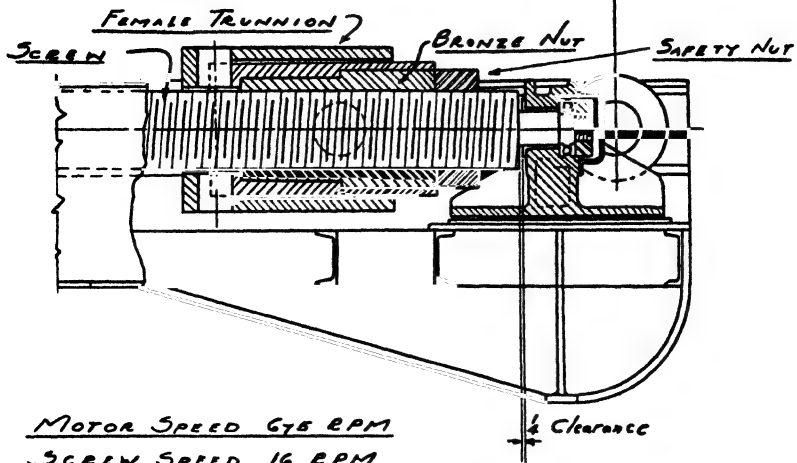
14'-10" Closed Position c. to c. Nuts (Boom High)
42'-0 Open Position c to c Nuts. (Boom Low)

Female Trunnion

Screw

Bronze Nut

Safety Nut

¼ Clearance

Motor Speed 675 RPM
Screw Speed 16 RPM
Nut Speed - 284 fpm
Max Load on Screw - 309,000#
Screw - 11½" O.D. 8¼ Root Dia

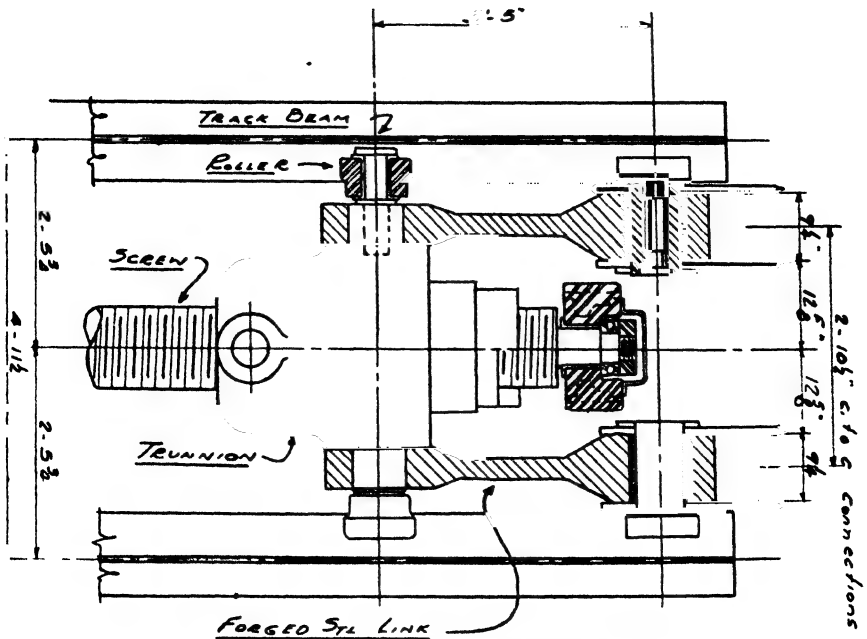



Fig. 15. Connecting details of boom luffing screw.

section the open side of which is braced with gussets and intermediate battens. Hinged to the platform trusses on a common pin with the boom foot, the lower end of the portal posts is provided with a pair of pin plates welded to the channels as indicated.

The top connection, through which the boom portal is hinged to the luffing gear, provides a very interesting detail. Consisting simply of two pairs of vertical plates separated by plate diaphragms, they are arranged for pre-fabrication and assembly. In their final position in the structure these built up connections form an integral part of the boom portal and provide a smooth transition of stress from boom chord to luffing gear and portal. This feature is further illustrated in the close-up photograph shown in Fig. 13. Layout and boring operations of the sturdy boom portal is accomplished in progressive stages on the fitting floor of the machine shop, where, in Fig. 14, a completed unit is shown ready for shipment.

Fig. 16. Luffing mechanism during assembly.

Luffing Screw and Frame—The luffing mechanism is one of the most interesting features of the crane. It consists of a screw arrangement of the turn-buckle type, the screw working two non-rotating nuts mounted in steel trunnions. Having an over-all length of forty-two feet from center to center of trunnions, the screw is made of forged nickel steel, normalized and quenched to provide a minimum yield point of 80,000-pounds per square inch. The threads are of the single lead buttress type, having a speed of 16 revolutions per minute and a nut speed of 2.84-feet per minute, permitting the boom to be raised from 90-feet to 60-feet radius in two minutes. The mechanism is motor driven through a gear reduction unit and so arranged that the boom cannot change positions except when the mechanism is in operation. Upper and lower boom positions are protected by an electric limit switch with slow down and final stop arrangements. Details of the end connections are shown in Fig. 15, while various parts of the mechanism are shown in the process of assembly on the machine shop fitting floor in Fig. 16.

The luffing mechanism is housed in a sturdy welded framework and guide arrangement, the nucleus of which is two longitudinal I beams with suitable cover plate. Rigid yokes are provided at each end near the hinge points

Fig. 17. Screw frame details.

Fig. 18. Side elevation of rotating structure.

with intermediate transverse frames, the details of which are indicated in Fig. 17. The design is so arranged that if the screw should break in tension, it will carry the load in compression to the bearings at the end of the framework, and thence through the frame, without dropping the load.

Longitudinal Trusses—The general arrangement of the longitudinal trusses, showing their relationship to the boom, screw-luffing mechanism and rotating platform, is shown in Fig. 18. The primary function of these units is to provide vertical bending and shearing resistance to the machinery platform. Framed between the rear bulkhead and the front portal, each truss consists of a pair of channels acting as top chord, three pairs of angles for diagonal web members and a bottom chord which utilizes the longitudinal platform beams as its sections. The gussets were shop welded to the top and bottom chords as indicated while the diagonal web members were shipped separately for final field assembly.

Details of the front portal are shown in Fig. 19, the vertical post of which transmits the boom foot reaction to the rotating platform. The posts consist of a pair of heavy channels separated by plate battens. Its upper

Fig. 19. Typical details of platform portal.

end is arranged to take the boom foot hinge pin while its lower end is provided with a simple base plate. The two portal posts are braced transversely with battened angles as indicated.

The lower end of the luffing gear is hinged to the rear bulkhead from which the stresses are transferred to the rotating platform and longitudinal trusses. Details of the rear bulkhead are shown in Fig. 20. In addition to acting as a distributing girder, each of the two side sections provides one of the walls of the two wing counterweight boxes which will be subsequently described. The photograph, Fig. 21, shows a boring operation for the hinge pins on one of the rear bulkheads.

The top chords of the two longitudinal trusses are braced laterally as indicated in Fig. 22. The location and arrangement of the various members are prescribed by the hoisting rope lead line clearance requirements. The cross struts of the bracing system provide the supports for two longitudinal monorail beams, the purpose of which is to provide machinery handling facilities. The connection details of the monorail beam to strut are interesting. As indicated, this connection is accomplished by means of a vertical round bar passing through one flange and inserted in the web of each beam. The bar is then continuously welded to the connecting perimeters, making an extremely simple yet highly efficient suspender connection.

Rotating Platform—The entire weight of the rotating structure and live load is supported upon a system of rolled steel, double flanged wheels. Bronze bushed, they revolve on steel pins assembled in a double channel circular cage. Heavy section crane rails form the upper and lower rail circles, the complete assembly resulting in a level, unyielding turntable.

General arrangement and details of the rotating platform framing are shown in Fig. 23. It consists essentially of four longitudinal girders, the center two of which form the bottom chords of the two longitudinal trusses previously described. The unit is spliced for shipment adjacent to the two center longitudinal beams, as shown in section B-B, resulting in three shipping sections. The roller reactions are supported by two transverse beams in the center section and four diagonal beams in the two wing sections. Additional transverse beams are provided for machinery, counterweight and king-pin supports. A plain plate covers the top of the center section

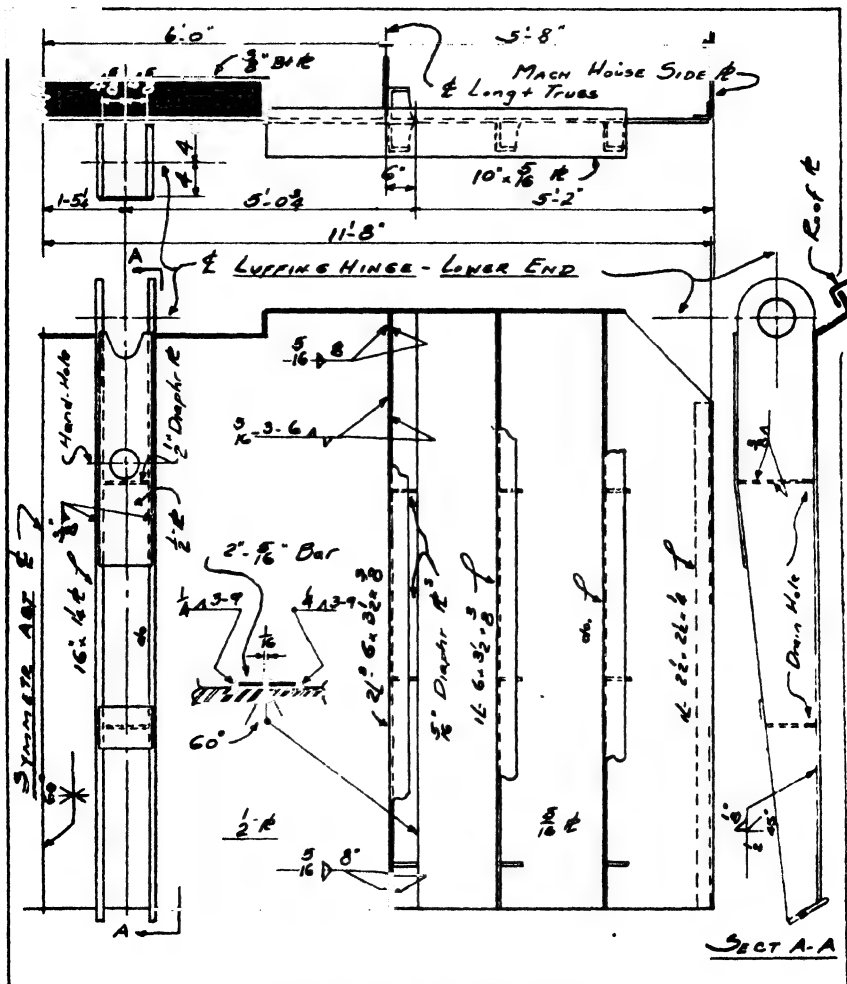



Fig. 20. Details of rear bulkhead.

while checkered floor plate is utilized in the wing sections Bottom flanges of all beams supporting the roller circle are further reinforced with a cover plate as indicated, the width of which, together with the top floor plate and properly spaced vertical stiffeners, insure ample resistance to any of the eccentrically applied roller loads

Section D-D, taken transversely and adjacent to the king-pin support is shown in Fig. 24, further amplifies the details of the platform construction. The arrangement of the structural supports for the swinger or rotating mechanism is detailed in section E-E

Fig. 21. Boring operation on rear bulkhead connection.

The photograph, Fig 25, a general view of the fitting floor, shows the gantry top in the foreground to which the lower rail, roller circle, rack and female stediment have been assembled The rotating platform is shown being turned over for mounting on the gantry top

A section through the rotating platform and gantry top, showing the center stediment, king-pin and swinger drive arrangement, is indicated in Fig. 26, while a floor plan of the machinery house, (See Fig 27), further illustrates the mechanical arrangement The center stediment, consisting of a bronze bushed male and female part, is mounted at the center of rotation of the crane and is designed to absorb all the horizontal forces due to rotation A hollow center king-pin passing through this stediment anchors the rotating platform to the gantry top and forms the center of rotation for the superstructure

The hollow center of the king-pin further provides for the carrying of the electrical wiring A four-ring collector, transmitting the main incoming current from the stationary to the rotating parts of the machine, and a multiple-ring collector, transmitting the control currents for travel and rail clamp controls, are fitted around the center stediment.

As indicated on the machinery plan, the motor driven rotating mechanism consists of a gear reduction unit, a set of bevel gears and a vertical shaft with an integral rack pinion, providing the structure with a rotating speed of one and one-quarter revolutions per minute

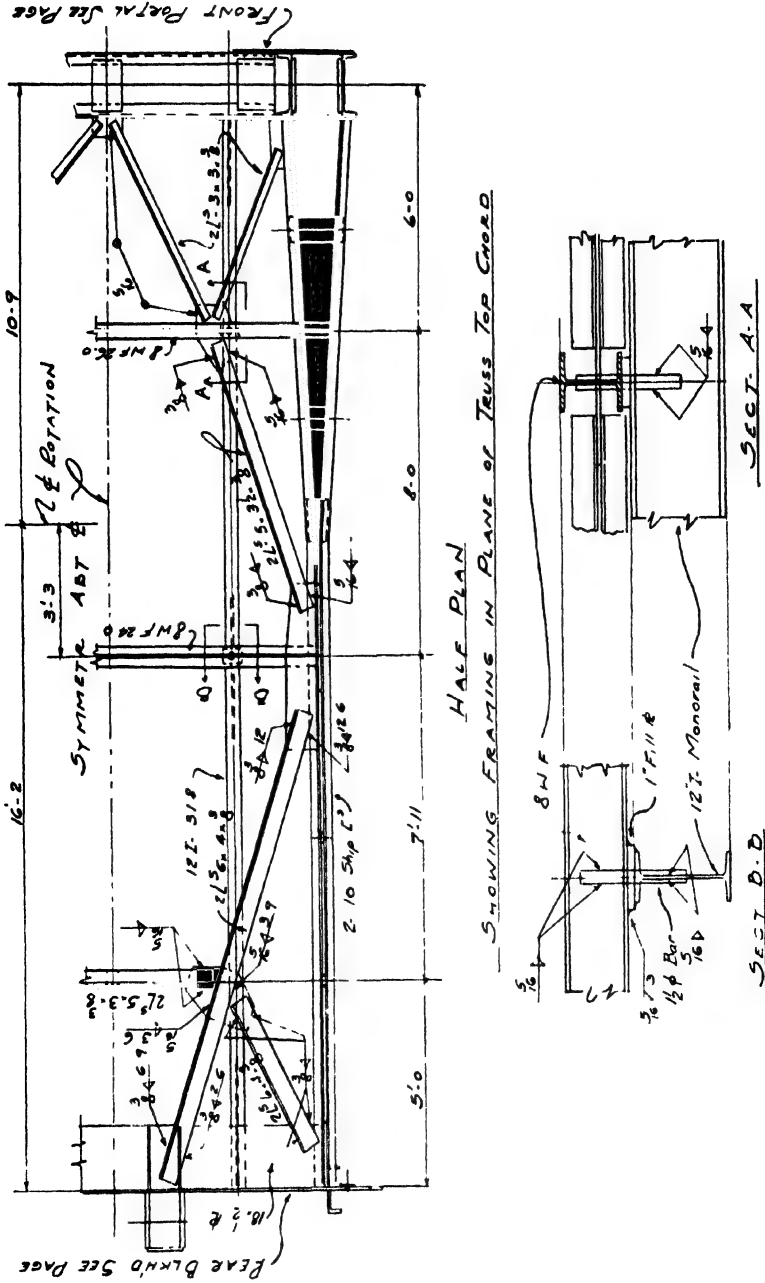



Fig. 22. Framing of truss top chord.

Fig. 28. Plan of framing for rotating platforms.

HALF TRANSV. SECT. THRU ROT. PLATE

SECT-D-D

LADDER DETAIL

Fig. 24. Half transverse section through rotating plate, ladder detail, and section through swinger.

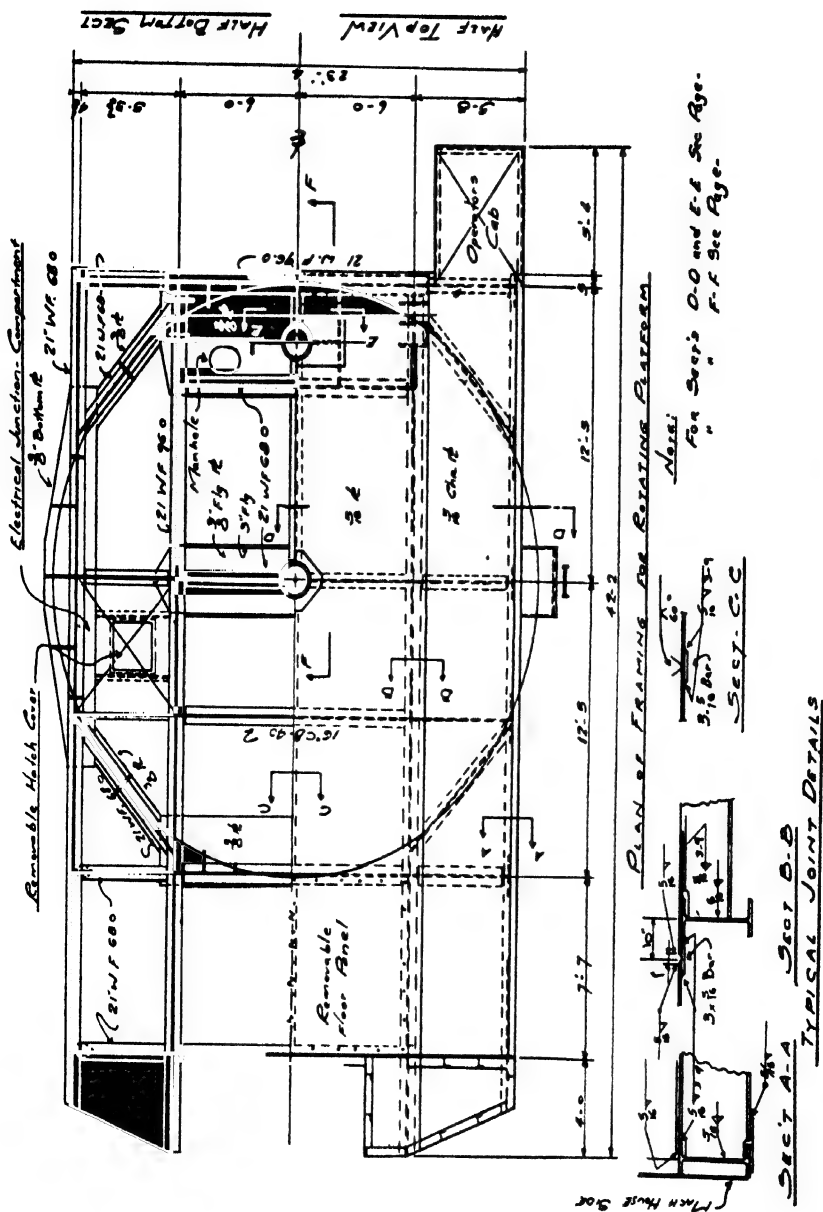



Fig. 25. Rotating platforms being turned over for mounting.

Driven independently, the main and auxiliary hoisting units are mounted on an integral welded base, the completed unit being illustrated in Fig. 28. The main hoist drum has a pitch diameter of fifty inches and a length of eighty-two inches. It is grooved to take a single layer of hoisting rope one and one-eighth inches in diameter, the main load block being reeved for four parts of line. The mechanism is powered with an electric motor through a double set of spur gear reductions.

The drum of the auxiliary hoisting unit has a pitch diameter of thirty inches and a length identical to that employed on the main drum, thus simplifying the base construction. The drum is grooved for the one-inch auxiliary block lead line.

Machinery House—The crane machinery, control panels and operator's controls are housed in a neat, all-welded steel cab, the general arrangement and details of which are indicated in Fig. 29. The side sections are built in 12-foot long panels, each consisting of two vertical sheets of heavy gauge steel. The sill of each section is a flat bar which is provided with two fitting holes for field assembly prior to welding directly to the top flange of the outside platform beams. The top-header or cave strut is made of a continuous angle or flanged plate, while the vertical edges of each sheet are backed up with four-inch I beams thus making a shipping section, the entire perimeter of which is rigidly supported. Midway between the sill and cave strut a four-inch horizontal girt cut from an eight-inch channel is inserted. Intermediate vertical stiffener bars are spaced on twenty-four-inch centers to add additional stiffness to the skin plating. The weight of the resultant section averages only ten pounds per square foot, which, for the

degree of strength and rigidity obtained, could be obtained only through welding.

The roof sections were built in similar shipping sections using 10-gauge roof sheets in seventy-two-inch widths. The rafters consisted of four-inch angles with toe welded to roof plates except at plate splices where four-inch I beams were employed, utilizing the flange as a back-up bar. The eave sections were trimmed with a continuous longitudinal bar. The resultant construction not only lends itself to simple fabrication methods but provides rigid, easy to handle, shipping sections.

Commercial steel sash of the projected ventilator type were installed in the sides of the cab by welding the sash frame to the skin plating with a continuous sealing bead making a neat, weather-tight joint. The location of the control cab and the arrangement of the windows provide the operator with a free and unobstructed view of the hooks for all positions of the boom. The control room is separated from the main machinery house by means of a metal partition, while floors, ceiling and sidewalls are insulated for the comfort of the operator and shatterproof glass is installed in the sash for his safety.

A removable panel is installed in the floor of the machinery house to permit any part of the crane machinery to be lowered to the trestle. The two longitudinal lift beams, described previously, span this opening.

Gantry Structure—The thirty-five foot high gantry structure is copped with a sturdy base on which are mounted the lower rail circle, the rack for the rotating mechanism and the female center stediment. The photograph, Fig. 30, shows the rotating platform being moved over to the gantry top for a check assembly before the crane is shipped. Careful manufacturing methods insure perfect alignment between the various sub-assemblies, thus the large roller circle, sandwiched between the sturdy welded gantry top and rotating platform, constitutes in effect a large roller bearing designed and perfected so as to give minimum friction in rotating the revolving structure and load. Details of the gantry top are indicated in Fig. 31. Four

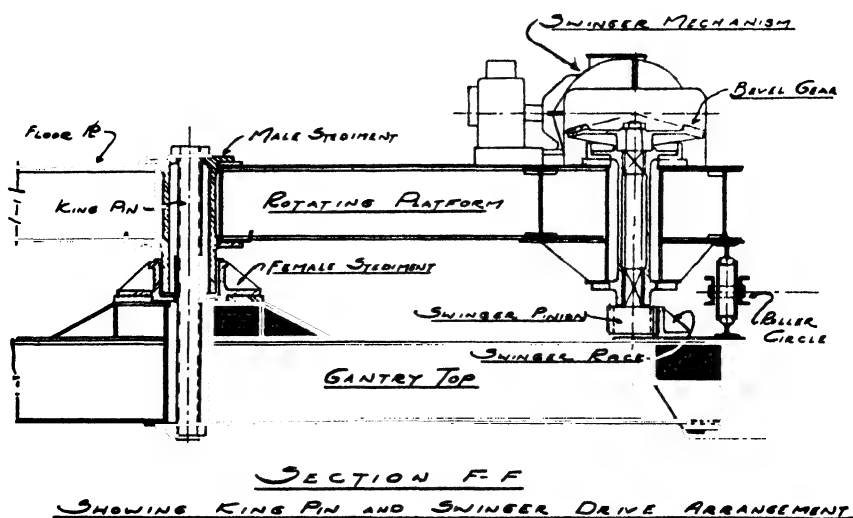



Fig. 28. King-pin and swinger drive arrangement.

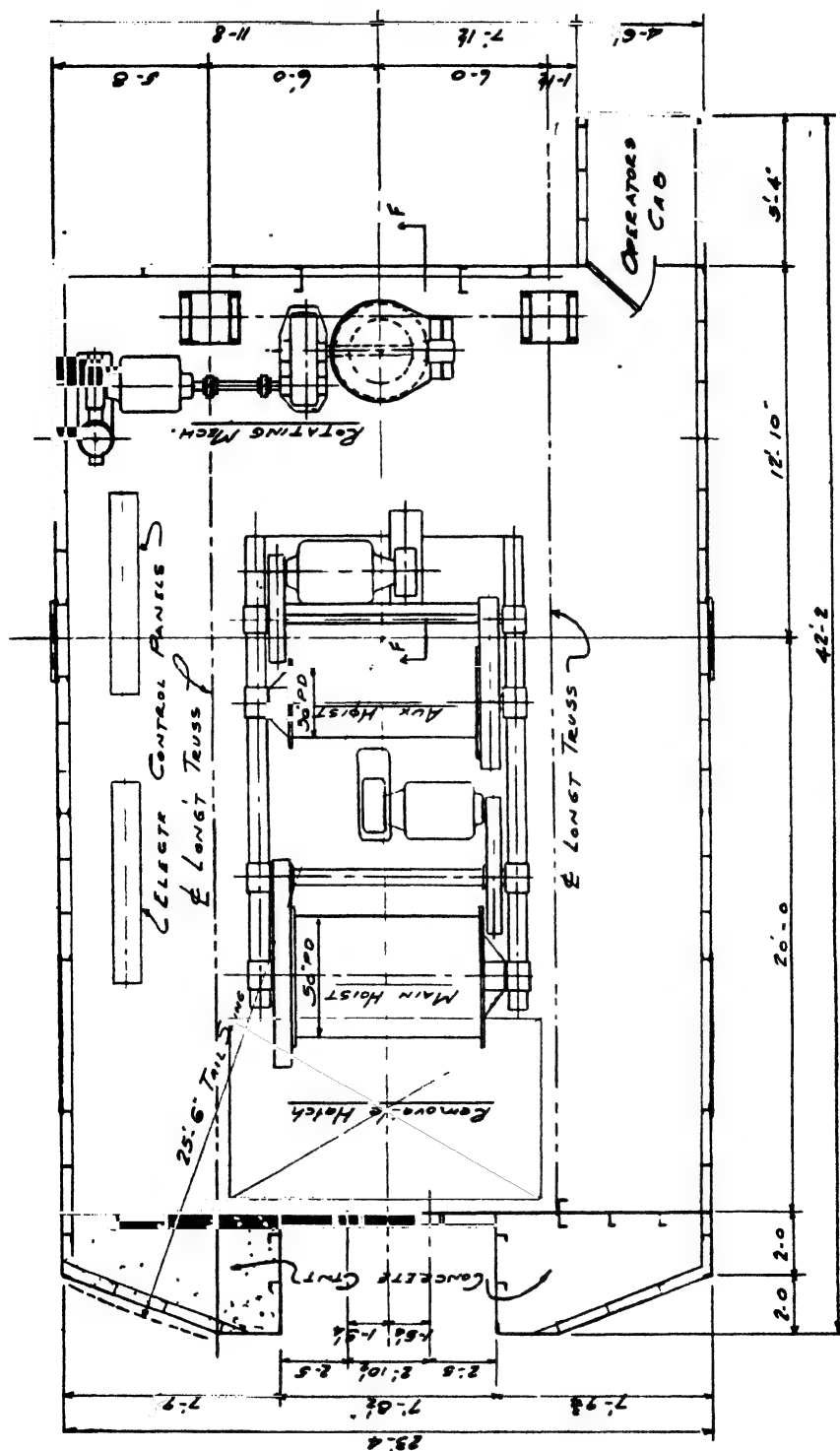



Fig. 27. Machine house floor plan.

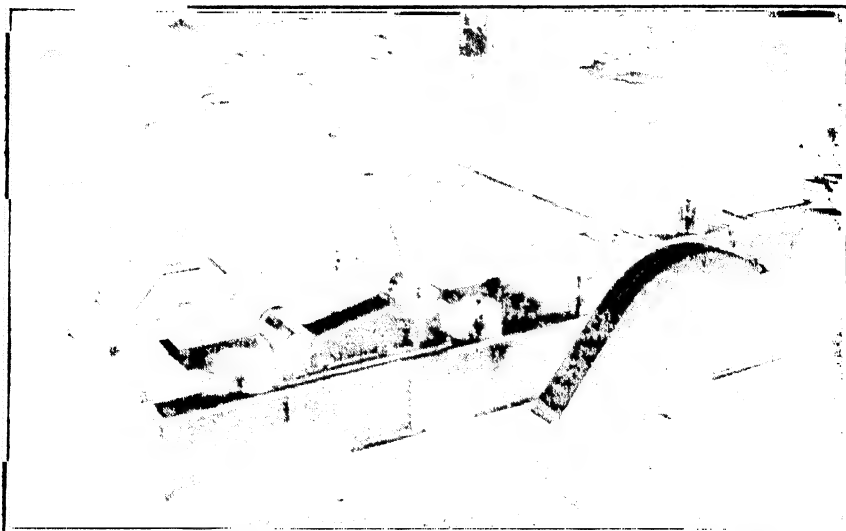



Fig. 28. Main and auxiliary hoists independently driven but mounted on one welded base.

Fig. 30. Rotating platforms ready for mounting.

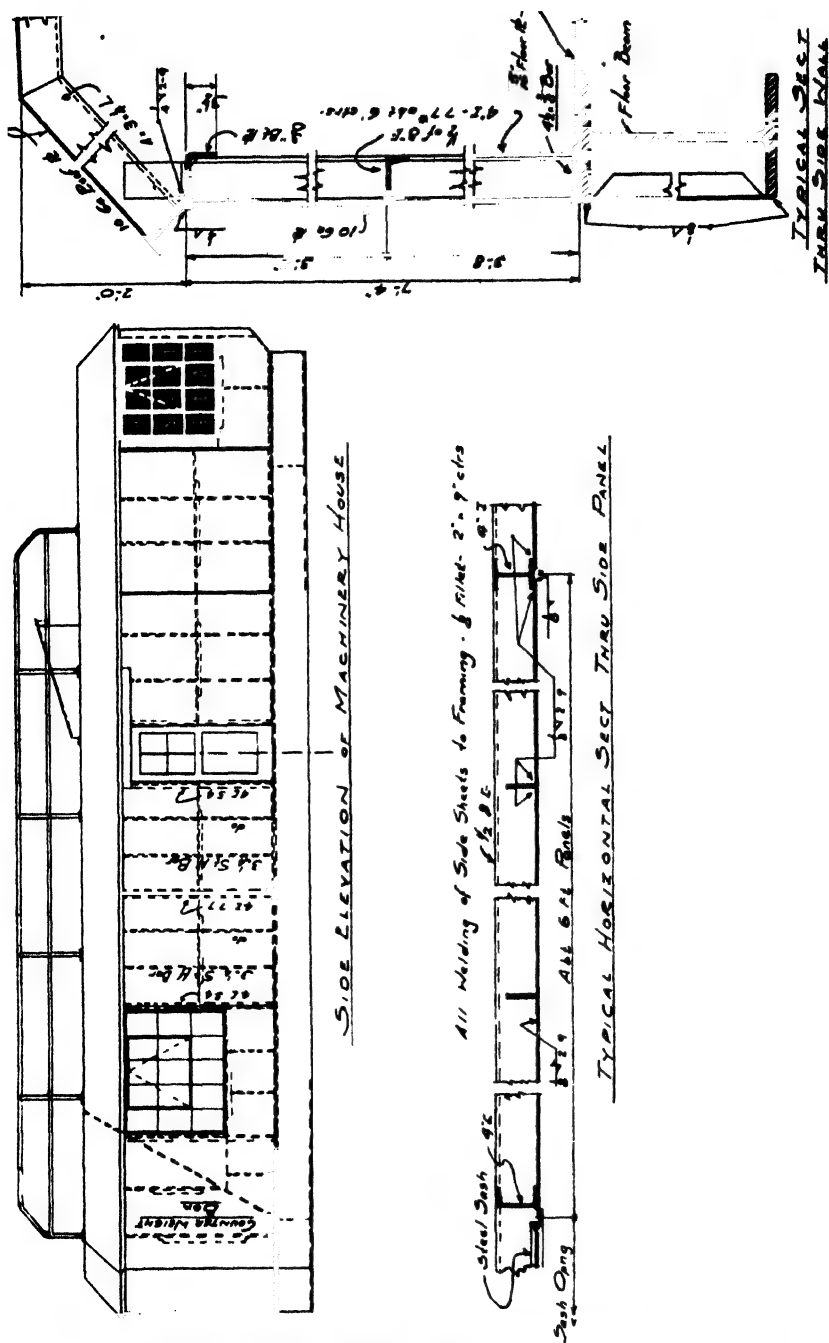



Fig. 28. Side elevation of machine house, typical section through side panel and typical section through side wall.

Fig. 31. Plan of gantry top.

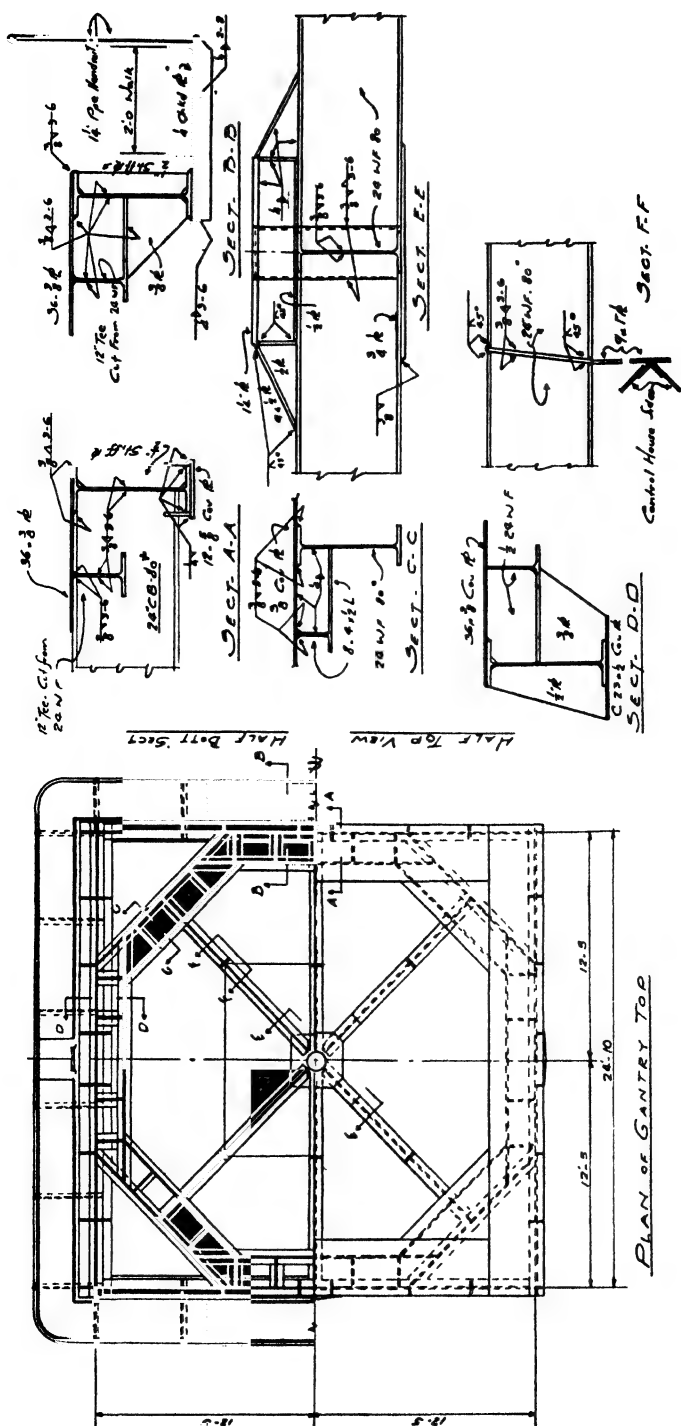
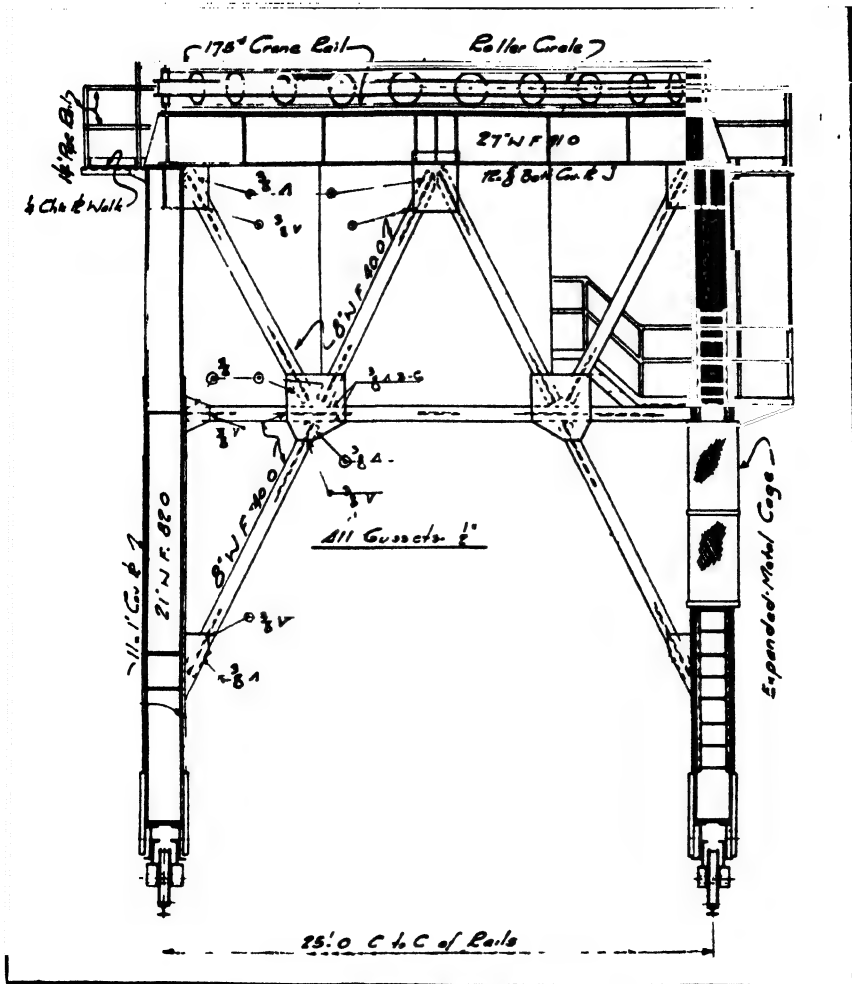



Fig. 32. Portal elevation of gantry.

main cap beams supported in the center of their spans by the side and portal trusses form the basic perimeter of the top platform. Section B-B shows a typical cross section through the main perimeter framing. A 12-inch tee cut from a 24-inch beam is used to support the rack section. Torsional resistance is obtained through the proper use of vertical diaphragms. Also illustrated are the construction details of the walkway and handrail which surrounds the gantry top. Diagonal beams of similar construction to the main side beams are arranged across the four corners of the platform to support the rail circle and rack. The platform is spliced for shipment at the center of the two side girders into two main field assembly units, while the central spider containing the supporting construction for the center stediment and king-pin constitutes the third shipping section. The splices for this center section are located and arranged to provide a simple support for the control house which is suspended from the gantry top. Details of this splice are indicated in section F-F.

The gantry portal elevation is shown in Fig. 32, indicating the general design and detail features of the portal framing. Similarly, the side elevation of the gantry is shown in Fig. 33. The gantry legs are pin connected to the four equalizer trucks at each corner of the gantry structure. The wheels are arranged in four-wheel fully equalized trucks, two of the wheels at each corner being motor driven through spur gear reductions. Each of the four travel motors are mounted on the outboard equalizer truck.

Two double-jaw automatic rail clamps, mounted in the center of the gantry sides, are sufficiently rugged to hold the crane against a 100-mile-per-hour wind. The rail clamps are pre-assembled in a self-contained all-welded housing, the assembly being illustrated in Fig. 34. The jaws of the rail clamp are actuated by a power unit consisting of a motor driven hoisting engine, and the mechanism is interlocked with the travel motor controls in such a manner that the operator must release the clamps before power can be obtained on the travel controls. The rail clamp release unit is located in the control house suspended from the gantry top.

History—The foregoing detailed description is a typical example of a long line of modern all-welded cranes being built by the crane and bridge department of our company. For more than 30 years we have been building revolving cranes, the design and manufacture of which was developed to meet the growing demand for faster and more suitable equipment for construction of dams, locks, bridges, terminals and all heavy work requiring the rapid handling of materials. Initially built largely of wood framing with steel hardware, the transition to all steel riveted construction produced a crane of greater lifting capacity at longer boom reach, and more rugged

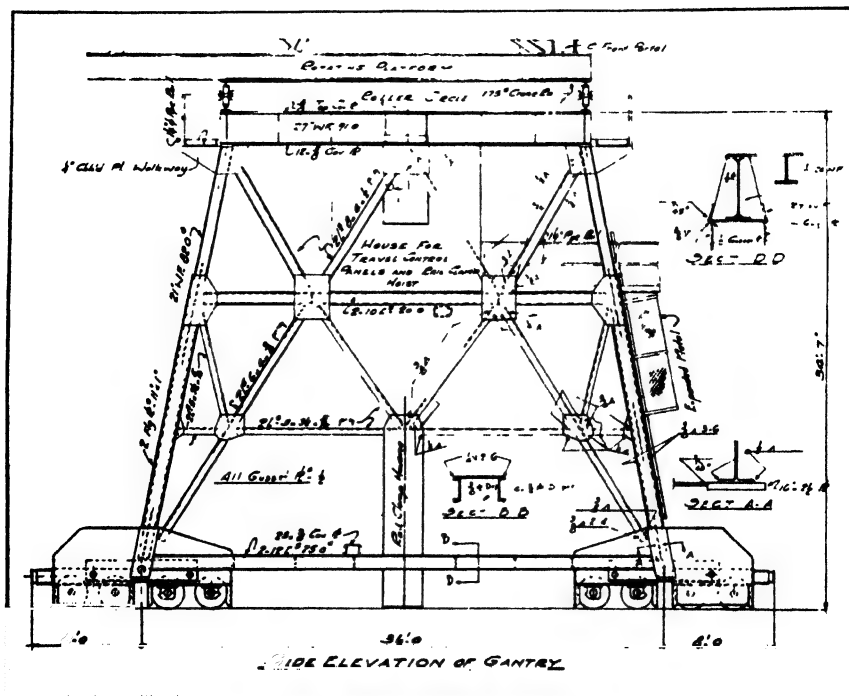



Fig. 33. Side elevation of gantry.

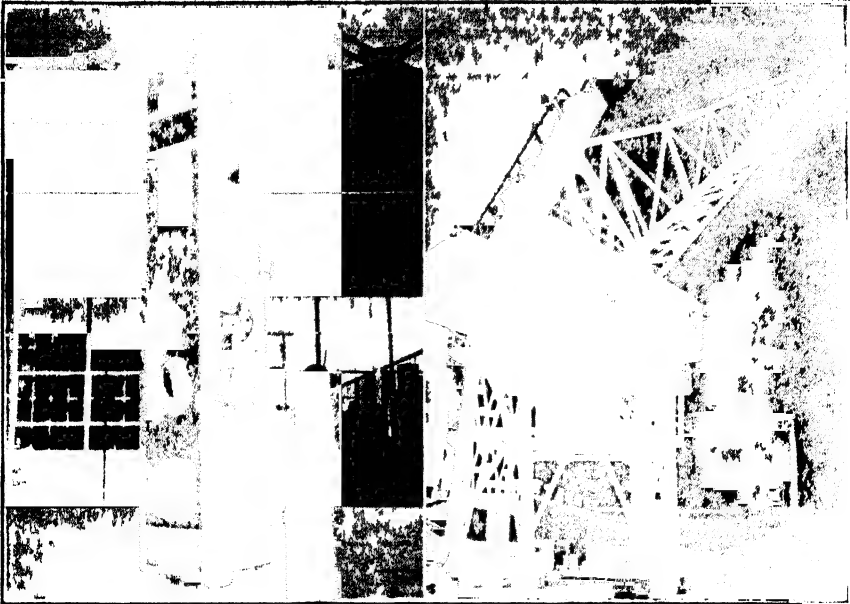



Fig. 34. (left). Self contained rail clamps for housing. Fig. 35. (right). Close-up of 28-ton screw luffing crane.

to meet severe and continuous service with low maintenance cost While various improvements were made from time to time in design and construction, probably no other procedure in manufacture has enjoyed as much attention and success on the part of our design engineers and management as that of modern arc welding Encouraged by executive support, and backed by a successful history which pioneered the application of welding to inland floating structures, it was only natural that we go "all-out" for welded construction on cranes, after having built a few experimental units early in 1940 The last riveted crane we built was mounted on a floating hull of welded construction This unit was completed during the latter part of 1939 Simultaneously, our preliminary designs of all-welded crane structures were progressing, and based on estimated savings over actual cost records for riveted construction, we ventured forth on the largest crane building program in the history of our company. The following comparative cost analyses, (See Tables I and II), illustrate the correctness of our judgment.

Cost Analysis—As indicated, the tabulation, Table I, contains comparative weight and fabrication data for both welded and riveted designs The weights and direct fabrication hours itemized for the welded design described in this paper are taken from actual cost records For the riveted design, each part of the crane was compared, item for item, with its welded counterpart, and the various members proportioned so as to give, as nearly as practical with riveted construction, comparable results as to strength, rigidity, etc. A net saving in weight of 12 per cent in favor of the welded design was established

TABLE I. Comparative Weight and Fabrication Data

Crane Part	Welded Design			Riveted Design		
	Weight Pounds	Direct Fabrication Hours		Weight Pounds	Direct Fabrication Hours	
		Per 100 lbs.	Total		Per 100 lbs.	Total
Boom Top Chord	5,200			6,100		
Boom Bott. Chords	10,900			10,900		
Boom Vert. Diag's.	7,600			8,000		
Boom Bott. Latl's.	2,800			3,000		
Boom Portal	5,200			5,200		
Misc. Parts and Details	12,728			17,500		
Total for Boom Struct. Parts	44,428	2.17	965	50,700	2.35	1,190
Boom Walk Supports	1,809			2,400		
Skywalk Mesh	800			800		
Pipe Handrail	700			700		
Total for Boom Walk	3,309	1.94	64	3,900	1.93	75
Cab Frame and Conn's	5,398			8,200		
Cab Sheeting	15,439			15,800		
Cab Trolley Beams	1,356			1,500		
Total for Machinery House	22,193	1.85	412	25,500	2.10	535
Front Portal	4,770			5,000		
Rear Blkh'd	7,740			8,400		
Top Chord Bracing	1,660			1,800		
Vert. Trusses	6,150			6,500		
Misc. Details	3,710			8,500		
Total for Platform Trusses	24,030	1.73	450	30,200	1.90	575
Rotating Platform—Main Mtl.	37,825			39,000		
Rotating Platform—Details and Conn's.	4,563			8,000		
Total for Rotating Platform	42,388	.95	402	47,000	1.15	540
Screw Frame—Main Mtl.	22,000			23,000		
Screw Frame—Details	2,444			5,000		
Total for Screw Frame	24,444	2.00	488	28,000	2.25	630
Gantry—Top Platform	31,942			34,000		
Gantry—Details	4,000			6,000		
Total for Gantry Top	35,942	1.06	383	40,000	1.20	480
Gantry Posts and Bracing	48,073			50,000		
Gantry Posts Details	6,400			9,000		
Total for G'try Posts and Bracing	54,473	1.25	683	59,000	1.35	800
Gantry Walks and Handrail	7,194	2.16	155	8,000	2.25	180
Hoist Base	6,373	1.47	94	7,200	1.75	126
Rail Clamp Box	5,570	2.64	147	6,300	2.75	173
Main Truck Equalizers	10,651	1.26	134	12,000	1.50	180
Truck Frames	9,570	2.15	206	11,000	2.50	275
Total for Misc. Items	32,164	1.81	581	36,500	2.06	754
Total for Crane Structure	290,565	1.57	4,583	328,800	1.74	5,759

TABLE II. Erection Cost Comparison

Part	Welded Design				Riveted Design			
	Operation	Hrs.	Wt. Tons	Hrs. per Ton	Operation	Hrs.	Wt. Tons	Hrs. per Ton
Crane Structure	Scaffold—Erect and Dismantle	56		.50	Scaffolf—Erect and Dismantle	70		.57
	Assemble and Erect	377		3.37	Assemble and Erect	420		3.40
	Bolt	50		.45	Bolt, Ream, Riv. (3700 Field Rivs.)	920		7.42
	Chip and Grind	14		.12				
	Fit and Tack	196		1.75				
	Weld	425		3.80				
	Total	1118	111.3	9.99	Total	1410	123.8	11.39
Boom	Assemble and Erect	175		7.32	Assemble and Erect	195		7.00
	Fit, Tack and Weld	129		5.40	Bolt, Ream, Riv. (540 Rivs.)	163		5.86
	Total	304	23.9	12.72	Total	358	27.8	12.86
Mach. House	Assemble and Erect	255		23.0	Assemble and Erect	280		21.9
	Fit and Tack	141		12.7	Bolt, Ream, Riv. (1230-½" θ Rivs.)	283		22.1
	Weld	105		9.5				
	Total	501	11.1	45.2	Total	563	12.8	44.0
	Grand Total	1923	146.3	13.2	Grand Total	2331	164.4	14.1

Summary

Item	Riveted Construction	Welded Construction	Saving Rivet-Welded	Rate in Dollars	Saving in Dollars	Per cent Saving
Material—Weight	328,800	290,565	38,235	$2.20	$ 800.00	12%
Fabrication Hours (Direct Labor)	5,759	4,583	1,176	1.80	1,940.00	83.5%
Erection Hours (Direct Labor)	2,331	1,923	408	2.75	1,100.00	21%
Total for Crane					$3,840.00	

$$\text{Saving per Ton of Welded Construction} = \frac{3,840}{146} = \$26.30$$

The direct fabrication labor hours for the various riveted items were obtained from unit cost records of previously constructed riveted cranes. A comparison of the total fabrication hours indicates a net saving of 23½ per cent in favor of the welded design.

Similarly comparative erection costs are tabulated, Table II, resulting in an additional saving of 21 per cent of the direct labor hours. A summary

of the results are also tabulated, indicating a gross saving of $3,840 per crane or an average saving of $26.30 per ton of welded crane construction. The labor rates used for both shop and field are average and include both direct and burden charges.

During two years we actually built a total of 63 all-welded revolving cranes, with capacities ranging from ten tons at 55-feet radius to 84-tons at 104-feet radius, and rail circles varying from 14-feet to 37-feet in diameter. The weight of these units totaled 7,524-tons of welded construction, which at the established rate of $26.30 per ton, amounts to a net saving of nearly $200,000 or an annual saving of $100,000.

While exact statistics are not available for the total tonnage of revolving crane structures in the entire industry, it is conservatively estimated that the annual weight would approximate 35,000-tons. Accordingly, a saving of nearly one million dollars annually would accrue if welded construction were generally adopted by the industry.

In addition to the economic advantages demonstrated above, indirect savings resulting from the lighter weight welded crane structures are apparent. Both travel and swinging motions will require less energy for operating their respective mechanisms, and foundations can be made lighter due to wheel load reductions. The extremely high degree of rigidity attained in the integrally welded parts promotes smoother performance for all of the various crane functions, and increased service life can be confidently assumed. These indirect benefits will be of substantial value to those desiring to reduce material handling costs.

In conclusion, the writer wishes to emphasize the fact that there has been a general tendency on the part of designers of this type of equipment to hesitate in applying welding to these structures because of the dynamic loading and stresses involved. We sincerely hope that the many features of welded design and construction submitted in this paper, together with the accomplishments typified by the numerous installations over the past two years, will encourage others to develop similar applications. As a fitting closure we submit a "close-up" of the subject crane, Fig. 35, amplifying many of its features. A tribute to welding progress, this rugged modern ship-building crane stands silhouetted against the sky, a symbol of a determined effort on the part of American crane designers and builders to supply the shipyards of our country with better erection equipment, which will expedite their program for the "bridge of ships."

Chapter IX—Welded Design of Tapered-Tube Booms for Cargo Ships

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Subject Matter: Booms of uniform cross section are unnecessarily heavy towards the extremities in order that they may have sufficient strength at the center of their length. Thus, there is an advantage in the proper proportioning of the boom regarded as a column with central load. A double telescopic arrangement of tubes having the ends of the larger elements swayed down to fit the smaller (to which they are welded) may be employed; or, alternatively two seam-welded tapering sections may be fabricated from plate and welded into a central splicing section on sleeve. Material, labor and overhead charges are all lower than in the case of the pipe boom of uniform diameter.

The present conventional design of booms for cargo ships consists of either three or five sections of two or three sizes, respectively, of standard I.P.S. or large outside diameter tubing. The tubes are swaged together with overlapped joints, the largest size tube forming the center section and the smallest sizes forming the end sections. The booms are generally symmetrical. In Fig. 1 are illustrated typical pipe booms and their joints.

This paper proposes the substitution of tapered-tube booms for pipe booms since it is possible to fabricate tapered-tube booms which have several design features which are superior.

The design of tapered-tube booms for cargo ships consists of two sections of tapered-tubing formed from steel plate. The large-diameter ends of the sections are butt welded together and a collar, formed of steel plate, is welded over the joint. The booms are not necessarily symmetrical. In Fig. 2 is illustrated a typical tapered-tube boom and its joint.

The booms are fastened to the cargo ship generally at an angle of 25 or 35 degrees with the horizontal. The outer end of the boom is supported by cables which, in turn, are supported from a vertical member known as the mast. This mast is rigidly fastened to the ship and may support several booms through boom-to-mast cables. The cables are operated through a winch so that the angle of the boom with the horizontal may be altered.

The cargo is picked up with a block-and-tackle arrangement which is supported from an end fitting on the outer end of the boom. The end of the cable passes longitudinally along the boom to the pivot end of the boom, thence over a pulley, and to another winch. Operation of this winch will lower or raise the cargo.

Two other block-and-tackle arrangements are fastened to the end fitting and supported from the boat. These are hand-operated and allow the boom to rotate about its pivot, thus permitting a cargo which has been raised from the dock to be revolved to a place over the hatch of the ship.

Principle of the Tapered-Tube Design—When the cargo is applied to the rigging arrangement, the boom becomes a compression column. A

column of uniform cross section will always fail at the center because the lateral deflections due to the end load are greatest at the center, thus producing the maximum bending moment and bending stress at the center. The bending stresses decrease as the distances from the center of the column increase since the lateral deflections are smaller. Thus a column of constant cross section designed for a safe working stress at the center will have unnecessarily conservative stresses at all other points.

The tapered-tube boom is designed to give as nearly as possible a uniform stress distribution throughout the length of the boom by using a suitable center diameter, material gage and taper. Thus, as the bending moments decrease away from the center of the boom, the cross section of the boom also decreases in nearly the same proportion, resulting in very nearly constant stresses throughout the length of the boom.

The pipe boom is designed according to the principles just mentioned by using sections of variable cross section. However, due to the cost of making swaged joints, only two or three sizes of pipe are economical to use in making the boom. Thus the stress in the smaller size pipe at a swaged joint and the stress at the center of the pipe boom are critical stress points. All other points on the length of the pipe boom have conservative stresses. Therefore, a pipe boom must necessarily be heavier to carry the same loads that a tapered-tube boom will carry since there is unnecessary material along the greater length of the pipe boom.

Fabrication of a Pipe Boom—The necessary lengths of pipe for the various sections of the pipe boom are cut to length from random pipe lengths of approximately 20- to 40-feet. Next, the ends of pipe to be swaged to smaller sections are heated to a dark straw color which is a sufficient temperature to permit a closely swaged joint. Drop forging presses are then used to perform the actual swaging operation. The circumferential weld is added after the joint has cooled, (See Fig. 1 for details).

Fabrication of a Tapered-Tube Boom—A sheet whose width is equal to the sum of the large circumference and the small circumference of the tapered-tube and whose length is equal to the length of one-half boom, is purchased. The sheet is laid out and sheared lengthwise into two equal trapezoids on a power-driven roll shear. Each of these blanks is used for fabricating a tapered-tube.

Next, each sheared sheet passes to the former. Here the sheet is clamped in position after which two, motor-driven, eccentric forming arms form the tube over a tapered mandrel to the shape of the final tapered-tube.

Now the formed tapered-tube is taken to an automatic welder which welds the longitudinal seam. This machine is operated by a variable-speed, reduction drive which pulls the tube longitudinally past the welding arc. Since the former makes a very accurate joint, no welding rod is necessary. The arc heat fuses the metal together from each side of the longitudinal seam without resulting in undercutting. An autogenizer flux is fed automatically to protect the weld from the ambient atmosphere.

Following this welding operation it is necessary to handweld the starting and finishing ends of the longitudinal seam.

Next, the tube goes to the cold-rolling machine. Here it is slipped over a tapered mandrel and cold-rolled by hydraulically-operated, radial rolls past which the tube must go. This cold-rolling increases the yield point of the steel from 28,000 to 48,000 minimum pounds per square inch. The ultimate strength of the steel is increased from 50,000 to 60,000 minimum pounds per square inch.
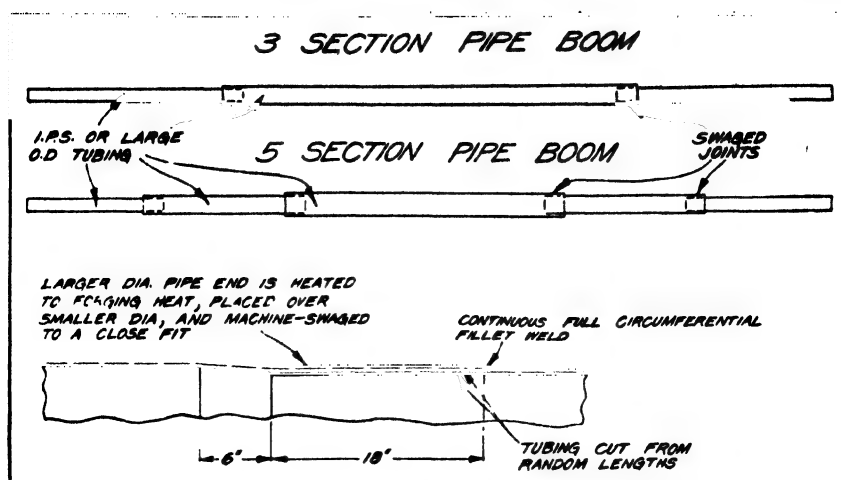
Fig. 1. Typical pipe booms and their joints.

Next, two of these finished tubes are placed with their large diameters together with a chill strip inside and fused by a hand-made circumferential weld. The weld is ground smooth and a rolled sleeve slipped over this assembly and held in place by circumferential fillet welds, (See Fig. 2 for details).

Fabrication Costs of Pipe Booms—No data are available on the manufacturing costs of pipe booms since they are manufactured by competitors. However, fairly accurate estimates should be possible by analyzing the operations. The following labor is estimated for fabricating the 5-ton pipe boom shown in the calculations in quantities of 100.

	No. of Men	Time per Section or Joint	Man Minutes
Layout, torch cut to length	1	8 min. per section 3 sections	24
Remove from furnace with crane, place section in proper location over smaller section in forge and swage	3	20 min. per joint 2 joints	120
Circumferential tack joints	1	4 min. per joint 2 joints	8
Circumferential weld joints	1	15 min. per joint 2 joints	30
Inspect	1	8 min.	8
Total direct labor in man minutes			190

Grade of labor required—Fair.

Fabrication Costs of Tapered-Tube Booms—The following labor is estimated for fabricating the 5-ton tapered-tube boom shown in the calculation in quantities of 100. The estimates are based on actual experience in fabricating booms and other tapered-tube sections and are therefore accurate. These labor hours are representative of the first tapered-tube booms produced as well as future tapered-tube booms.

	No. of Men	Time	Man Minutes
Shear one sheet for two tubes	2	.9 min. 1 pair	1.8
Form to tapered tube	2	1.6 min. 2 tubes	6.4
Weld longitudinal seam	1	22 min. 2 tubes	44.0
Weld ends of longitudinal seam	1	5 min. 2 tubes	10.0
Cold roll	2	8 min. 2 tubes	32.0
Inspect	1	8 min. 2 tubes	16.0
Roll sleeve	1	4 min. 1 pair	4.0
Roll chill strip	1	2 min. 1 pair	2.0
Insert chill strip and tack two tubes together	2	5 min. 1 pair	10.0
Weld tubes together	1	15 min. 1 pair	15.0
Grind weld	1	10 min. 1 pair	10.0
Locate sleeve and circumferential tack both ends	1	7 min. 1 pair	7.0
Circumferential weld both ends of sleeve	1	28 min. 1 pair	28.0
Total direct labor in man minutes			186.2
Grade of labor required—Fair.			

Burden Costs of Fabricating Pipe and Tapered-Tube Booms—Again no figures are available on the overhead costs in manufacturing pipe booms. Suffice to say, the overhead on the automatic machines cannot run over a fraction of the cost of operating the drop forge while at the same time operating and supplying fuel for the furnaces necessary to heat the pipe section ends for swaging.

Material Costs of Pipe and Tapered-Tube Booms—No definite price schedule is set up on the price of pipe and large outside diameter tubing in large quantities. However, from what information the writer was able to gather, its price varies from 3½ to 4 cents per pound in quantities sufficient for one hundred 5-ton pipe booms. Since the pipe boom weighs 1950 pounds, the material cost at 3½ cents per pound will be $68.25. Adding in 10 per cent scrap loss in cutting from random lengths, the material cost becomes $75.07.

The tapered-tube boom uses plates which, in the quantity desired, will cost base price of $2.10 per 100-pounds. Since the tapered-tube boom weighs 1628-pounds, the material cost at 2.1 cents per pound will be $34.19. No scrap loss will occur.
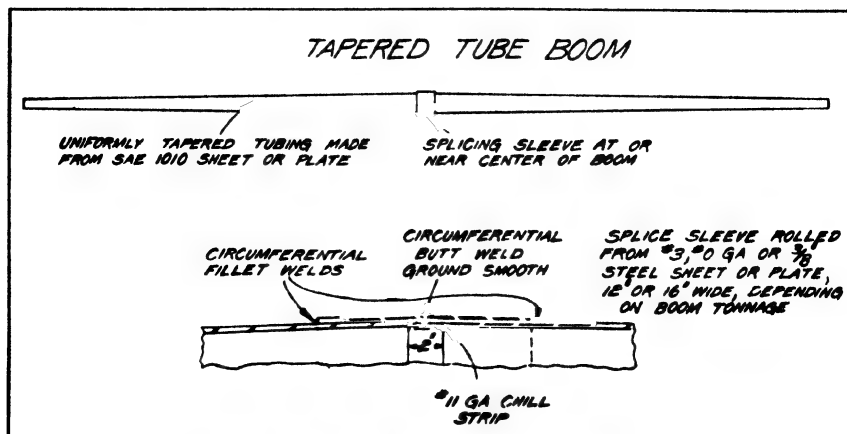
Fig. 2. Typical tapered boom and its joint.

Proportionate Cost Savings on 5-Ton Tapered-Tube Boom Over Pipe Boom

Material cost savings $= \frac{75.07 - 34.19}{75.07} = 54\%$

Labor savings $= \frac{190 - 186.2}{190} \doteq 2\%$ (Estimated)

Burden savings 50% or more (Estimated)

Proportionate Cost Savings on All Tapered-Tube Booms Over Pipe Booms

Material cost savings = 50%
Labor savings = 5 to 10% (Estimated)
Burden savings = 50% or more (Estimated)

Estimate Total Annual Gross Cost Savings Accruing from the Use of Tapered-Tube Booms Instead of Pipe Booms—According to "Marine Engineering and Shipping Review" for April, 1942, page 228, there are scheduled for completion in 1942 and 1943, 1478 EC2 "Liberty"-type cargo ships in addition to some 500 other oceangoing cargo ships. All indications are that these schedules are being met or bettered. Each of these ships has anywhere from 10 to 14 cargo booms varying in capacity from 5 to 50 tons. Therefore, there will be approximately 1000 cargo ships averaging 12 booms per ship or a total of 12,000 booms needed in the next fiscal year.

At least 90 per cent of the recommended pipe booms can be replaced by tapered-tube booms showing material cost savings in proportion to their tonnage. The material savings on the 5-ton boom amounts to $40.88 so it should be very conservative to say that an average material saving of $60.00 per boom should result. If we manufacture 10,800 of these booms which would represent only a small fraction of our capacity, the savings in material cost would be at least $648,000 per year. Add to this the appreciable labor and burden savings, particularly on the replaced five-section pipe booms which require four swaged joints, and the annual savings should run well over $800,000 per year.

Comparative Advantages of Tapered-Tube Booms Over Pipe Booms—1, They are stronger. In all cases they are designed to have a higher factor of safety based on yield point stress. The service life is thus increased since the tapered-tube boom is able to absorb larger shocks than the pipe boom. Failures do occasionally occur in pipe booms in testing or operation on cargo ships because of shock overloads. 2, They are cheaper. 3, They weigh less. The weight saved may be replaced with additional cargo, thus resulting in more tonnage per trip. 4, They may be purchased with better delivery schedules in emergencies. Stock warehouse sheets may be purchased and sheared to the required size whereas the probability of obtaining large outside diameter pipe in the required sizes and quantities is not good.

Chapter X—Experimental 7½-Ton Refrigeration Plant

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Subject Matter: A plant for use in a college laboratory is provided with arrangements, such as thermometer wells, for measuring quantities which affect its operation. Arc welding was used for the greater part of the ammonia piping system. Instead of using elbows, the pipe was heated and bent to about 10-inch radius. The cost of this piping system was $51. The cost using usual methods with pipe threading would be $70, the saving being 27%.

This refrigeration plant is experimental in that it is provided with devices for measuring all of the quantities which affect its operation and students can make experimental tests on it. The plant is not operated continuously but is used for student instruction at times when its operation will bear out some principle which is being studied in the refrigeration theory courses. The plant, therefore, stands idle part of the time, but is ready to operate whenever it is needed.

One of the essential requirements of this type of operation is that the ammonia piping system should remain perfectly gas-tight with very little care or inspection. This requirement was met by bending all the ammonia pipes to fit in their respective places and then arc welding them in place. All screw fittings were eliminated except the valves to control the flow of the ammonia and the screw connections into the various pieces of apparatus. By this means it was possible to reduce the number of points at which leaks could occur to a minimum and at the same time the easy bends and welds give the whole plant a rather pleasing appearance.

When the installation was completed, it was checked for leaks with air pressure and was found to be air-tight. It was then filled with ammonia and after several months no ammonia has been lost from the system showing that it is still perfectly tight.

It is the belief of the writer that the methods which were used in the installation of this refrigeration plant are a great deal simpler than the old method of cutting and threading the pipe and using screw fittings. And the piping is a single unit, except for the control valves and the connections to the equipment. Although no repairs to the piping have, as yet, been necessary, repairs can be very easily made by pumping the ammonia out of the section where the repairs are to be made, cutting out the pipe, bending a new piece to fit and welding it into place. Additions to the piping can be made at any time by the same method. There is no need to unscrew a lot of fittings to get at the desired piece of pipe.

Fig. 1 shows a schematic diagram of the piping. There are three systems

of piping shown in the drawing: (1), the steel pipes for the refrigerant shown by double or solid lines; (2), the pipes for supplying and measuring the ammonia condenser cooling water, shown by long dashes; (3), the brine circulating system, shown by short dashes. This paper deals largely with the first system because it is the only one in which welding was used to replace the screw fittings. The other two systems use galvanized pipe which is not so suitable for this kind of treatment.

Starting at the ammonia compressor the gaseous refrigerant is compressed to a pressure of approximately 150-pounds per square inch. The compression warms the gas and at the same time oil from the compressor is apt to be picked up so the gas is passed through a device for separating the oil. The gas then passes into the condenser where it is cooled and condensed to liquid ammonia. The liquid settles to the bottom of the condenser and flows into the ammonia receiver where it is stored until needed. A pipe leading from the bottom of the receiver draws off the liquid ammonia and it is led to an expansion valve where its pressure is lowered as it expands into the brine cooler. Heat from the brine evaporates the ammonia and the vapor is drawn off by the compressor to start the gases through the cycle again.

The heat which is given up by the ammonia when it condenses is taken up by water which is circulating in the tubes of the ammonia condenser. This water, which is supplied from the city water mains, passes through the condenser tubes due to the city water pressure and is discharged into either of two 4- x 4- x 4-foot tanks to be measured volumetrically. Drainage from these tanks is allowed to run to waste.

The brine is stored in a galvanized tank 4- x 4- x 8-feet and is drawn off
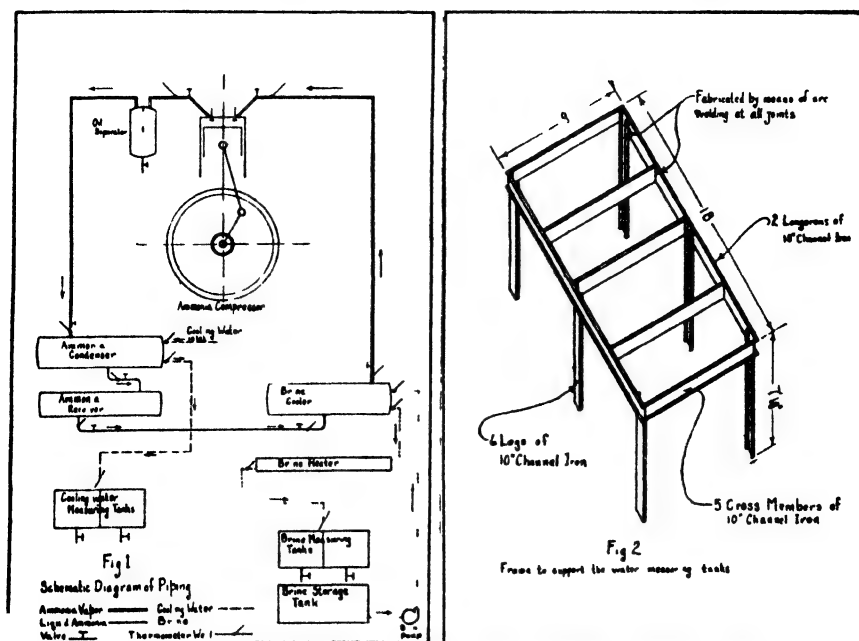
Fig. 1, (left). Schematic diagram of piping. Fig. 2, (right). Frame to support the water-measuring tanks.

by a centrifugal pump which discharges into the tubes of the brine cooler. In the brine cooler the ammonia absorbs heat from the brine, cooling it to the lowest temperature in the system. Since the whole plant is for experimental purposes there are times when no ice is being made and at such times it is necessary to heat the brine in the brine heater shown in Fig. 1. When the brine leaves the brine cooler it passes through the tubes of the brine heater and from there it goes to either of two 4- x 4- x 4-foot tanks for volumetric measurement. Drainage from these tanks is returned to the 4- x 4- x 8-foot storage tank.

In order to conserve the floor space and to obtain a more compact unit the 4- x 4- x 4-foot measuring tanks were installed on a deck 7-feet 10-inches above the floor level of the other equipment. The deck was supported on a framework of 10-inch channel irons shown in Fig. 2. The various pieces were cut from standard stock channel iron and were fabricated entirely by electric welding. The two longerons and the six legs were cut to the proper lengths. The legs were then placed back to back against the longerons as shown in Fig. 3. Clamps were placed so as to hold them steady and they were adjusted in position till they were correctly located and were perfectly square with the longerons. Tack welds were made at each of the corners, then beads were run clear around to secure a very strong and sturdy joint. In order to properly align the cross-members between the longerons, the structure was assembled in an upside down position. The longerons were placed on the floor with the legs in a vertical position. Temporary supports were provided to keep the structure square and in proper alignment. Blocks were placed under the longerons so that they were parallel. The cross-members were then put into place and tacked, one after the other till all five were in place. Beads were then run along the corners and filled till the proper strength was obtained.

The structure was then turned right side up, located in the proper position on the floor and concrete was poured around the bottom of the legs to hold them in place. Although no triangular bracing was placed in the structure there is very little swaying showing that this type of construction is strong and rigid. The wooden deck, on top of the structure to support the measuring tanks, was not put in place till after the equipment had been installed on the main floor.

The main floor plan of the refrigeration equipment is shown in Fig. 4. The equipment is placed so as to simplify the piping as much as possible. In most cases the pipes come out of one piece of equipment and connect directly into another piece.

A gas-fired forge, shown in Fig. 5, was made to heat the ammonia pipes for bending. These pipes were ½-inch and one-inch extra heavy weight and could not be bent without heating. A table, having a firebreak top, was built of angle iron and pipe using electric welding throughout. An upright was placed at one corner of the table to support the burner. The burner was constructed as shown in the detail on Fig. 5. The burner is a simple mixing device for natural gas and air from compressed air tanks and a compressor. The gas and air were supplied to the burner through rubber hoses so that the forge could be moved from place to place. Loose fire bricks were placed upon the table about the piece to be heated so as to form a furnace and retain the heat. By simply shifting the bricks it was possible to build up a furnace to heat pieces of a large variety of shapes. After a few minutes of pre-heating the bricks, the forge would heat a piece of pipe in just a few minutes to a cherry red, this being the correct

temperature for bending. Measurements showed that the flame and furnace temperatures were around 1700 to 1900° F.

In order to handle the fire bricks on the forge it was necessary to make a special pair of tongs as shown in Fig. 7. The parts of the tongs were cut to size, bent to the proper shape and electrically welded together.

Various schemes for bending the pipe were tried and the most successful one was to heat the part of the pipe which was to be bent. The pipe was then removed from the forge and gripped with two bending irons as shown in Fig. 6, being careful to grip the pipe far enough away from the heated portion so that the bending irons would not dent the hot pipe. Pressure from the hands of the workman on the bending irons resulted in a clean bend of approximately 10-inch radius and it was a simple matter to secure any desired degree of bend. No difficulty with kinking the pipe was experienced although that is the first thing an inexperienced person would expect.

Whenever it was possible to do so the exact shape of the pipes was determined by measurements of the position of one piece of equipment with respect to the other. Full scale sketches were then made on the concrete floor with chalk. The heated pipe was placed over the sketch and could be bent to the required shape with little difficulty. The pipe was then tried in place and any slight changes in shape could be made before the piece had completely cooled. Any large amount of bending always required re-heating.

To the uninitiated it might seem that with this method of bending the pipes it would be hard to secure a good fit but the writer had never bent a pipe before the job was started, yet it was surprising how easily the pipes could be made to fit into place, and line up and give a pleasing appearance.

Whenever the openings in the equipment were provided with screw
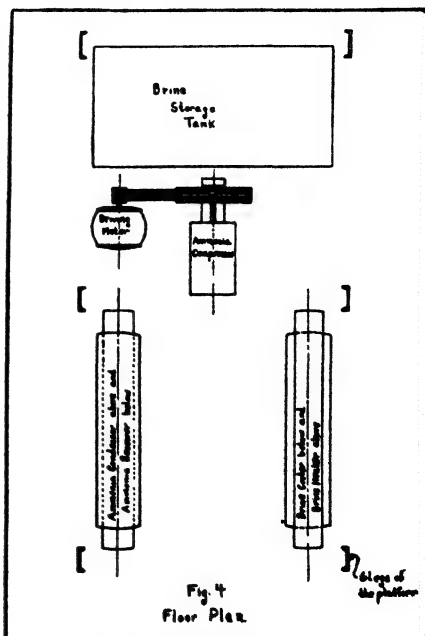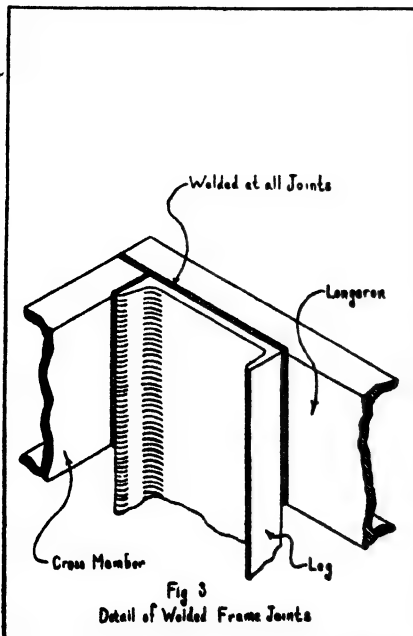
Fig. 3, (left). Details of welding frame joints. Fig. 4, (right). Floor plan.

connections it was necessary to make short pieces of pipe with threads on one end and bevel them for welding on the other. These stubs were made long enough so that the heat from the weld would not loosen the threads. The threads were coated with a rather thin mixture of litharge and glycerine and were screwed into place. The pipes were cut off square and then beveled in order to secure good penetration for the weld. Fig. 8 shows the cross section of a weld. The best results were obtained by running a small bead with plenty of heat all the way around in the bottom of the groove. The groove was then filled using a moderate amount of heat, running a good bead clear across the groove. Extreme care was necessary to make sure the welding puddle did not cool at the edges between traverses of the welding rod across the groove. Any appreciable cooling was almost sure to result in pinhole leaks. It was necessary to start a new puddle about two ridges back from the end any time that the arc was discontinued. Also, at the end of the weld, after the pipe had been completely encircled, it was necessary to lap over the first part of the weld a little, being careful to have a good full puddle before the arc was broken off.

Whenever it was possible to do so each weld was tested with air pressure as soon as it had cooled, to determine whether any leaks were present. Whenever pin-holes were found a round nose chisel was used to gouge out the pin hole. The hole was then filled with a good hot bead and little difficulty was encountered in stopping the few pin-holes that were found.

In order to measure the temperature of the ammonia at various places in the system it was necessary to make thermometer wells and weld them in the piping. Fig. 9 shows the two kinds of wells which were used, one for a horizontal location and the other for a vertical location. The procedure in making the wells was to thread the pieces of quarter-inch pipe and cut them off about 4-inches long. The unthreaded end was heated in the gas fired forge and peened over till it was nearly closed. The hole was closed with a small weld. The piece was then tested for leaks with air pressure. The body was then cut to length, heated and peened over. The quarter inch pipe was welded into one end of the body and the other end of the body was welded shut. A hole was cut in one side of the body and one of the stub pipes shown in Fig. 8, was welded into place. The stub was then screwed into an air pressure connection to test the body for leaks. A thin solution of soap and water was used to show up any pin holes. When the body was shown to be tight a hole was cut on the opposite side of the body, exactly in line with the stub pipe, then the stub pipe was screwed into an outlet and the pipe line could be welded into the hole. By testing each weld before the next piece was applied it was possible to eliminate any chance for leaks in the finished thermometer wells.

Comparison of Cost—In order to compare the cost of welded construction with other methods of fabrication, standard construction practice was resorted to whenever practicable. For instance, standard refrigeration screw fittings could have been used in place of bending the pipes and welding them. Also, in the case of the steel structure to support the tanks on the upper deck, fabrication could have been accomplished with various sorts of splices which could have been bolted into place.

The cost of welding was figured from data in "Procedure Handbook of Arc Welding Design and Practice." In some cases it was necessary to make approximations because there was no data on the exact type of weld which was being made. In each case, a comparative method is discussed
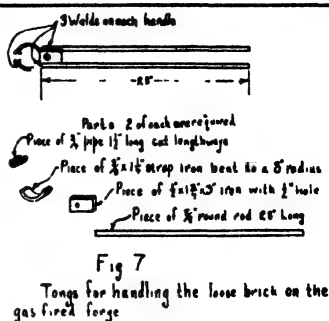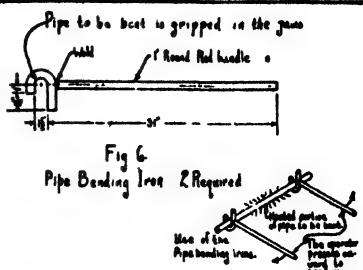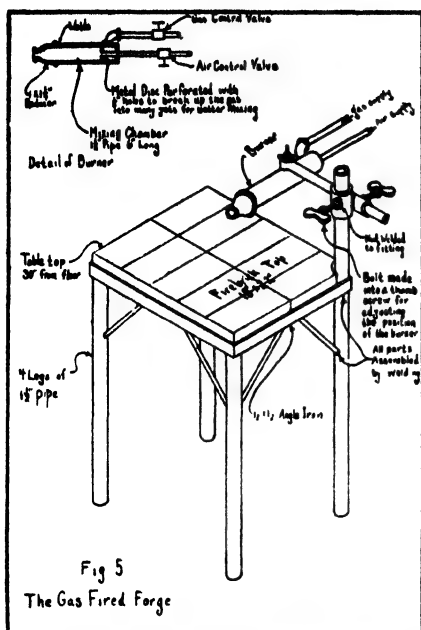
Fig. 5, (left). The gas-fired forge. Fig. 6, (right above). Pipe bending iron; Fig. 7, (right below). Tongs for handling loose brick.

drawing largely from the experience of the author in the estimation of the time required to do the various operations required.

In order to estimate the cost of welds made manually with a shielded arc the following assumptions are made:

Labor	$0.75	per hour
Power	$0.02	per Kw. Hr.
Electrodes	$0.095	per lb.
Efficiency of machine	50%	

Cost of Fabricating the Steel Frame to Support the Water Measuring Tanks—In Fig. 3 the detail of a welded corner of the steel structure is shown. In order to fabricate this corner by means of bolts, instead of welding it would be necessary to drill holes through the web of the leg and through the web of the longeron and bolts could have been inserted in the holes to hold the pieces together. More holes could have been drilled through the flange of the leg and through the web of the cross-member using more bolts. Referring to Fig. 2 it is seen that six joints could have been made by this means. The two remaining cross-members could have been bolted into place using pieces of angle iron in the corners.

The purpose of the frame was to support the tanks for volumetrically measuring the condenser cooling water and the brine. The measuring was done in four tanks 4- x 4- x 4-feet and two of the tanks were placed at either end of the frame so as to be supported by the end cross-member and the the one next to the end, each member supporting half of the weight. A floor of 2-inch x 6-inch lumber was built on top of the frame and the tanks rested on the floor. In order to estimate the strength required at each joint it must be assumed that there would be times when all four tanks would be full of water at the same time and the joints would have to be made

strong enough to support this weight with an allowable degree of safety. The volume of water in the two tanks at either end is 4 x 4 x 4 x 2 = 128 cubic feet. Water weighs approximately 62.4 pounds per cubic foot and this would be 128 x 62.4 = 7990-pounds or roughly 8000-pounds. The tanks were made of ¼-inch thick steel plate and weighed 720-pounds each, or 1440-pounds on each end of the steel frame. The total weight of the floor was 840-pounds and this weight was approximately the same on each of the five cross-members or 168-pounds on each. The American Standard channel iron from which the structure was made weighed 15.3-pounds per foot and this makes the weight of the 9-foot cross-members 137-pounds and the 18-foot longerons 274-pounds. The weights which each cross-member would have to support is shown in the following table:

The two end cross-members:

Weight of water	4000 lbs.
Weight of tanks	720 lbs.
Weight of floor	168 lbs.
Weight of cross-member	137 lbs.
Total	5025 lbs.
Or roughly	5000 lbs.

The two cross-members next to the ends support the same amount.
The middle cross-member would support:

Weight of floor	168 lbs.
Weight of cross-member	137 lbs.
Total	305 lbs.

The two end cross-members are supported by the two end legs and using a safety factor of 6 and remembering that each leg would take half the weight, the force to be transmitted by the bolts is:

$$\text{Total force} = \frac{6 \times 5000}{2} = 15{,}000 \text{ lbs.}$$

The allowable shearing stress of bolts is approximately 9000 pounds per square inch and the total area required for the bolts is:

$$\text{Total bolt area} = \frac{15{,}000}{9{,}000} = 1.66 \text{ sq. in.}$$

The area of a ¾-inch bolt is .441-square inches and four bolts would have an area of 1.766-square inches which is a slight error on the side of safety.

In like manner it can be shown that the number of bolts required for the various joints would be:

End cross members to the legs	16
Next to end cross-members to longerons	32
Middle cross-member to middle legs	4
Longerons to end legs	8
Longerons to middle legs	12
Total number of bolts	72

The bolt size is ¾- × 1½-inches.

Cost of 72 bolts ¾- × 1½-inches	$ 7.88
Cost of 72 lock washers size ¾-inch	4.61
Total cost of bolts	$12.49

In order to insert the bolts it would be necessary to drill holes in the various pieces. Assuming a drill press to be available the various pieces would have to be moved up to the drill press and set into place for drilling. This work is assumed to be about equal to that which was required to set the pieces in proper alignment for welding so that this part of the cost of one method about offsets the cost of the other method and need not be compared.

The actual cost of drilling the holes can be estimated using twice the number of bolts for the number of holes to be drilled because two pieces are bolted together with each bolt. Assuming an average of 2 minutes to locate and center punch each hole the total time would be:

$$\text{Center punching time} = \frac{2 \times 144}{60} = 4.8 \text{ hours}$$

Assuming $0.75 per hour for the labor this is $3.60. The time required for drilling the holes can be estimated assuming the cutting speed of structural steel to be 100-feet per minute with a feed of 0.010-inches per revolution of the drill. The circumference of a ¾-inch hole is 2.36-inches and to get a cutting speed of 100-feet per minute a drill speed of 510 revolutions per minute would be required. With a feed of 0.010-inches per turn the drill would advance 5.1-inches per minute. The average thickness of the metal to be drilled is ¼-inch and if another ¼-inch is allowed for the depth the point of the drill would have to advance before it cuts a full diameter of the hole this would give ½-inch of drill travel per hole. The total drill travel would be ½- × 144- = 72-inches. And the time required would be 72 ÷ 5.1 = 14.12 minutes. Assuming $0.75 per hour for the labor of the drill press operator this would be (14.12 × 0.75) ÷ 60 = $0.18. This assumes no wear and tear on the drill press, breakage of drills, power cost, etc.

After drilling the holes it would be necessary to assemble the frame. This would likely require two men. Assuming 10 minutes per bolt for aligning the holes, and inserting and tightening the bolts this would be (10 × 72) ÷ 60 = 12 hours. Assuming each operator receives $0.75 per hour this would be 2 × 0.75 × 12 = $18.00.

The total cost of bolting the frame together can be summarized thus:

Item	Cost
72—¾-inch × 1½-inch Machine Bolts	$ 7.88
72—¾-inch Lock Washers	4.61
Cost of centerpunching 144 holes	3.60
Cost of drilling 144—¾-inch holes	0.18
Cost of inserting and tightening bolts	18.00
Total cost	$34.27

Referring again to Fig. 3 it can be seen that the length of weld necessary in each corner is four times the depth of the channel iron plus four times the width of the flange or

$$4 \times 10 = 40.0$$
$$4 \times 2.625 = 10.5$$

Total........ 50.5-inches

All six legs were joined to the frame by means of the same kind of a weld making a total of 50.5- × 6- = 303-inches of weld. The two cross-members
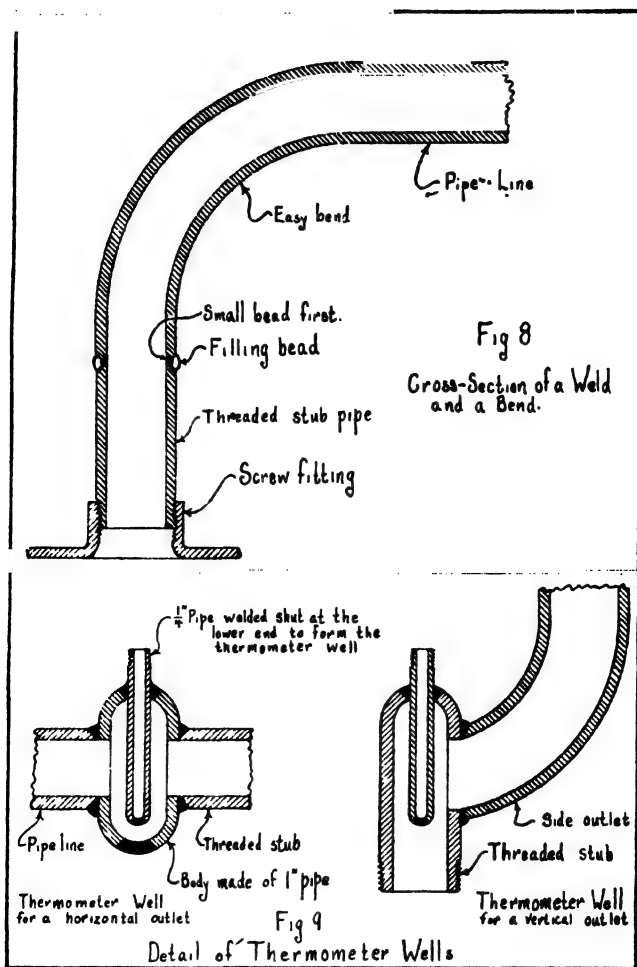
Fig. 8. (above). Cross section of welded end bend; Fig. 9. (below). Detail of thermometer wells.

next to the ends were joined to the longerons by four welds which were 15¼-inches each or a total of 61-inches. The total length of welds in the frame was:

$$\frac{303 + 61}{12} = 30.33\text{-feet.}$$

The welds were similar to those described in the "Procedure Handbook" covering lap and fillet welds, vertical position and the following information was obtained from that source:

Joint	¼-in. plate
Passes	1
Electrode size	5/32-in.
Current	130 amp.
Minimum Volts	25
Welding speed, ft./hr.	18
Lb. of electrode per ft. of weld	.23

The actual cost of welding the steel structure can be estimated thus:

Labor = .75 ÷ 18 = ... .04166
Power = (130 × 25 × .02) ÷ (.5 × 70 × 1000) = .00186
Electrodes = .23 × .095 = ... .02185

Total cost per foot.. $.06537

Since there is 30.33-feet of weld the total actual cost of welding was 30.33 × .06537 = $1.98. This cost is based on actual welding time only, no time being allowed for fatigue of the operator, changing of electrodes, fit-up, etc. Omitting the fit-up the other factors can be assumed to increase the cost by about four times making the actual cost $7.92. It was assumed under the bolt construction that the fit-up time for welding was approximately equal to the handling time for drilling and assembling so this part of the cost need not be considered.

Cost of Assembling the Ammonia Pipes—In Fig. 1 a simplified schematic diagram of piping is shown. The ammonia piping is the only part of the system which was assembled by bending and welding and this part will be compared with assembly by means of screwed fittings.

A count of the various bends and connections which were actually made showed that the following pieces would be required if they were made up by means of screw fittings:

	For 1-Inch Pipe Number	Cost	For ½-Inch Pipe Number	Cost
Tee	9	$4.86	4	$1.64
Elbow	13	4.68	16	4.32
45° Elbow	8	3.60	8	2.56
Union	3	1.95	7	2.87
4-in. nipple	9	0.90	3	0.21
Total costs		$15.99		$11.60
Total cost of fittings		$15.99	+ 11.60 =	$27.59

The time required to assemble the pipes and fittings can be estimated, determining the time for the various operations. There would be 70 pieces of pipe necessary to connect the fittings together.

	Total time
Determining the location of fitting and measuring the length of pipe, 10 min./pipe	700 min.
Cutting off the pipe, 2 min./cut	140 min.
Cutting threads on each end of pipe, 15 min./pipe	1050 min.
Starting threads and tightening pipe into fittings, 5 min./pipe	700 min.
Total time	2590 min.
To this should be added about ¼ of the estimated time for incidentals	647 min.
Total time	3237 min.

At 75 cents per hour this would be: $\frac{3237 \times .75}{60}$ = $42.00 for labor.

No valves for controlling the flow of the ammonia is included in this estimate because the same number of valves would be required by either method of assembly.

In order to assemble the ammonia pipes by bending them to fit and welding them into place without screw fittings the time was consumed thus:

	Total time
Measuring the position of one outlet in relation to the outlet to which it was to be connected, 10 outlets..	10 min./out—100
Laying out full scale sketches on the floor	20 min./out—200
Heating the pipe, 45 bends	5 min./bnd—225
Making the bend, 45 bends	2 min./bnd—90
Trying the pipes in place, 17 pipes	10 min./pipe—170
Re-bends, heating and bending 23 bends	7 min./bnd—161
Cutting off pipes, 17 pipes 1 end	2 min./cut—34
Cutting holes for Tee outlets, 13 Tees, 2 min./Tee	26
Total time	1006 min.
Incidentals to be added (1/4 of total time)	251
Total time	1257 min.

Cost of bending and fitting pipes at 75 cents per hour for 3 men:

$$\frac{3 \times 1257 \times .75}{60} = \$47.16$$

In order to keep the gas fired forged ready for use as it was needed for heating the pipes it was kept going continuously. The consumption of natural gas was approximately 170-cubic feet per hour at a cost of 40 cents per 1000-cubic feet making the cost of the gas:

$$\frac{1257 \times 170 \times .40}{60 \times 1000} = \$1.424.$$

The average weld that had to be made on the pipes was a 60-degree V'd butt weld and the following information was taken from the "Procedure Handbook:"

Kind of joint, 1/2-in. pipe	1-in. pipe
Wall thickness, .147-in.	.179-in.
Electrode size, 1/8-in.	1/8-in.
Current, amps., 100	110
Minimum arc volts, 23	24
Actual welding speed, ft./hr., 22	20.5
Lb. of electrode per ft. of weld, .25	.30

Cost of welding 1/2-inch pipe:

Labor = .75 ÷ 22 =	.03410
Power = (100 × 23 × .02) ÷ (.5 × 22 × 1000) =	.00418
Electrodes = .25 × .095 =	.02375
Total cost per foot	$.06203

There were 19 welds on the 1/2-inch pipe making a total length of weld of 50.16-inches or 4.18-feet. The total cost of these welds was 4.18 × .06203 = $.259.

Cost of welding 1-inch pipe:

Labor = .75 ÷ 20.5 =		.03658
Power = (110 × 24 × .02)	(.5 × 20.5 × 1000) =	.00515
Electrodes = .30 × .095 =		.02850
	Total cost per foot	$.07023

There were 15 welds made on the 1-inch pipe making a total length of weld of 53.82 inches or 4.48-feet. The total cost of these welds is 4.48 × .07023 = $.3146.

This cost is based on actual welding time only, no time being allowed for fatigue of the operator, change of electrodes, fit-up, etc. These factors can be assumed to increase the cost of welding by about four times or 4 × (.259 + .3146) = $2.39.

The total cost of assembling the ammonia pipes by bending and welding is thus:

Labor for bending and fitting	$47.16
Natural gas for the forge	1.42
Welding	2.29
Total cost	$50.87

Cost of the Gas-Fired Forge—A coal-fired blacksmith's forge having a capacity about equal to that of the gas-fired forge which was built for this installation can be purchased for $45.00.

An alternate method of construction would have been to have made the legs of angle iron instead of pipe and to have bolted the legs to the angle iron tip. The angle bracing could have been bolted to the legs and to the top. Framework could have been built up and bolted into place to hold the burner. And the burner could have been built up from standard pipe fittings. Cutting the pieces to length for bolted construction would probably cost about as much as cutting the pieces for welding as shown in Fig. 5, and need not be compared. Also the cost of material is about
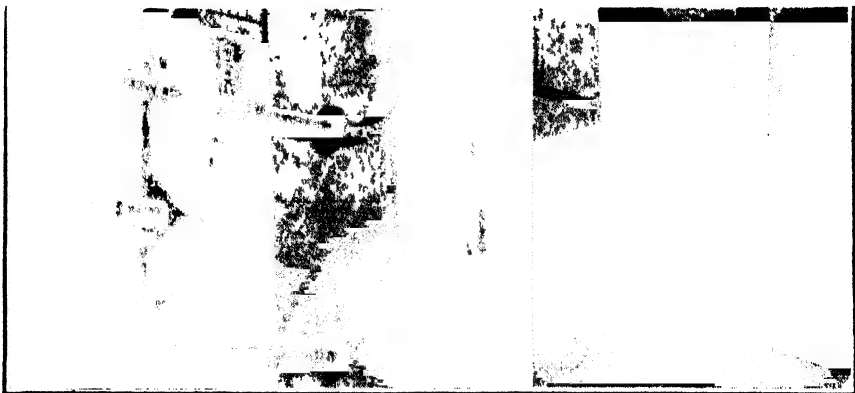
Fig. 10, (left). Welding in one corner of steel framework. Fig. 11, (right). Bent pipes.

the same in either case. The cost of the other items which are comparable can be estimated as follows:

Cost of 26—3/8-inch × 1-inch machine bolts $0.68
Cost of drilling 52—3/8-inch holes, at 5 min. per hole for locating, center punching, and drilling 2.60
Assembling the parts, inserting and tightening bolts .... .75
Pipe fittings for the burner
1—1¼-inch × 1-inch reducer .... .15
1—1¼-inch × 4-inch nipple .... .11
1—1¼-inch × ½-inch × ¾-inch reducing Tee .... .26
Assembling the burner and getting it to work .... .75

Total cost $5.30

The cost of welding on the gas fired forge can be broken down into several steps. The table top was made of 1½-inch x 1½-inch x ¼-inch angle iron welded in each corner. The top was welded together in a flat position and part of each weld was flat and part was vertical. At each corner the flat part was $\sqrt{1.5^2 + 1.5^2} = 2.12$-inches and the vertical part was 1½-inches and for all four corners the welds were:

Total vertical = 1.5 × 4 = 6-inches.
Total flat = 2.12 × 4 = 8.48-inches.

For a vertical butt weld the "Procedure Handbook" the following information is given:

Kind of joint	¼-inch
Passes	1
Electrode size	⅛-inch
Current, amps	110.
Minimum arc volts	25
Actual welding speed	15-ft./hr.
Lbs. of electrode/foot	.24

The cost of this kind of a weld per foot is:

Labor = .75 ÷ 15 = ... .05000

$$\text{Power} = \frac{110 \times 25 \times .02}{.5 \times 15 \times 1{,}000} = \text{........ } .00733$$

Electrodes = .24 × .095 = ... .02280

Total cost per foot $0.08013

Total cost of vertical welds on the table top = ½ × .08013 = .0400

For the part of the welds on the table top, which were made in the flat position, the "Handbook" gives:

Kind of joint	¼-inch
Passes	1
Electrode size	5/32-inch
Current, amps	130
Volts	25
Welding speed	17.5-ft./min.
Lb. electrode/foot	.11

The cost of this kind of a weld per foot is:

Labor = .75 ÷ 17.5 = ... .04280

Power = $\frac{130 \times 25 \times .02}{.5 \times 17.5 \times 1,000}$ = ... .00744

Electrodes = .11 × .095........................ .... .01045

Cost per foot...$0.06069

Total cost of flat welds on the table top is .06069 × $\frac{8.48}{12}$ = $0.0428

Total cost of welds on table top = .040 + .0428 = $0.0828

Welding 4 legs and 1 upright column of 1½-inch pipe to the angle iron top required a total length of weld of

$$\frac{5 \times 1.9 \times 3.1416}{12} = 2.49 \text{ feet.}$$

The wall thickness of the pipe may be found from the inside and outside diameters:

Outside diameter.. 1.900
Inside diameter.. 1.610

.290

The wall thickness is half of this or .29 ÷ 2 = .145 inches.

The weld which was used in this case was for fillet welds, flat position:

Kind of joint	.145-inch pipe on ¼-inch plate
Passes	1
Electrode size	¼-inch
Current, amps	190
Minimum arc volts	30
Actual welding speed, ft./hr.	45
Lbs. of electrode per foot	.155

The cost of this kind of a weld per foot is:

Labor = .75 ÷ 45 = ... .01660

Power = $\frac{190 \times 30 \times .02}{.5 \times 45 \times 1,000}$ = ... .00506

Electrodes = .155 × .095 = ... .01472

Cost per foot...$0.03638

The total cost for welding the legs and upright to the table top is
.03638 × 2.49 = $0.0904

The braces for the legs were ½-inch rod welded to the leg on one end and to the angle iron on the other. The circumference of a ½-inch rod is .5 × 3.1416 = 1.573-inches. Eight rods were used and were welded on both ends making a total length of (1.573 × 8 × 2) ÷ 12 = 2.10-feet. The table was turned for each weld so that the weld was in the flat position. This makes the set-up similar to the V'd butt weld flat position, if it is assumed that penetration is half way through the rod at all times. This is the same kind of weld as that which was used to weld the flat parts of the corners of the table top and cost $0.0609 per foot. In this case the total cost of welding the leg braces is:

0.0609 × 2.10 = $0.1274.

In order to make the two thumb screws shown in Fig. 5 it was necessary

to weld handles on half-inch bolts. The length of the weld on each was twice across the head of a half-inch bolt plus twice the thickness of the handles or:

$$2 \times .75 + 2 \times .1875 = 1.875\text{-inches.}$$

There are two handles and the total length is:

$$(2 \times 1.875) \div 12 = .313\text{-feet.}$$

The welding procedure is tabulated in the "Handbook" for a 5/16-inch plate and the cost figures up to $0.03636 per foot. This brings the welding of the thumb screws to:

$$.313 \times .03636 = \$0.01135.$$

The fitting to clamp the burner to the support was made by welding two half-inch nuts to short pieces of pipe and welding the two pieces of pipe together. Total length of weld is all the way around two ½-inch nuts and approximately 4 inches to weld the two pieces of pipe together or

$$2 \times 6 \times 7/16 + 4 = 5.25 + 4 = 9.25\text{-inches.}$$

Cost per foot is assumed to be equal to the cost of welding the handles onto the bolts for the thumb screws or $0.03636.

$$\text{Total cost} = (9.25 \times .03636) \div 12 = \$0.028.$$

The burner was made of various thicknesses of material and the average thickness can be assumed to be approximately 5/16-inch and the average weld is a fillet weld, flat position making the cost $0.03636 per foot. The length of the weld is:

Around a 1½-inch pipe to weld the reducer to the pipe = 1.9 × 3.1416 =	5.98-inches
Around a 1½-inch pipe to weld the plate on the back end of the burner = 1.9 × 3.1416 =	5.98-inches
Two welds around a ⅜-inch pipe for the air supply = 2 × .675 × 3.1416 =	4.25-inches
Welding the bolt for supporting the burner to the burner = ½ × 3.1416 =	1.57-inches
Total length	17.78-inches

$$\text{Total cost of welding} = (17.78 \times .03636) \div 12 = \$0.0538.$$

The total cost of all the welding on the gas fired forge can be summarized thus:

Corners of table top	$0.0828
Legs and upright column	0.0904
Leg braces	0.1274
Handles on thumb screws	0.0114
Nuts on fitting and fitting	0.0280
Burner	0.0538
Total cost of welding	$0.3938

This cost is based on actual welding time only and other factors entering into the cost would bring the cost up to:

Welding cost	$0.3938
Labor and incidentals	3.0000
Total cost of the forge	$ 3.39.

Fig. 6 shows a special tool which was made to facilitate the pipe bending. This tool would not be needed in the event of erection of the ammonia pipes with screwed fittings and the cost of making this tool is added to the cost of the bending and welding method without having any counterpart

Fig. 12. Two welded thermometer wells at inlet and outlet to ammonia compressor. Fig. 13. Welded thermometer well in horizontal location.

in the former method with which its cost can be compared. The cost of these two irons can be estimated thus:

79 inches of 1-inch diameter round rod	$1.40
Cutting the pieces from the bar	.15
Heating and bending the jaws	.35
Welding the jaws to the handles*	.02
Total cost	$1.92

*Estimated for a plain butt weld in the flat position with 50% penetration.

Fig. 7 shows a pair of tongs which was made to handle the bricks on the gas fired forge furnace. Pieces of stock material were used to make the various parts and these parts were welded together. A pair of tongs of approximately the same size and shape could have been purchased on the open market for $2.00.

The price of the tongs as they were made was:

Cost of material	
Small piece of ¾-inch pipe	$0.0288
2 Jaws	0.1000
2 Hinge pieces	0.1180
2 Handles	0.3870
Cutting the material to lengths	0.3500
Bending the jaw pieces	0.2000
Drilling the hinge holes	0.5000
Welding	
Lips on jaws	0.0197
Jaws on hinges	0.0133
Hinges on handles	0.0520
Total cost	$1.7188

Fig. 9 shows the welding on the thermometer wells These wells could

have been made up using standard pipe fittings and the cost would have been:

For location in a horizontal outlet:
2—1-inch Tees—(extra heavy) $1.20
2—Thermometer wells 1.50
For location in a vertical outlet:
5—1-inch Tees—(extra heavy) 3.00
5—Thermometer wells 3.75
Screwing the fittings in place 0.75

Total cost $10.20

The cost of welding the thermometer wells can be estimated thus:
For a horizontal outlet:
Welding the closed end of the ¼-in. pipe $0.00926
Welding the bottom of the body shut 0.01313
Welding the ¼-in. pipe into the body 0.00464
Welding the well into the pipe line 0.01808

Cost for 1 well $0.04511

For a vertical outlet:
Welding the closed end of the ¼-in. pipe $0.00926
Welding the ¼-in. pipe into the body 0.00464
Welding on the side outlet pipe 0.00904

Cost for 1 well $0.02294

Cost of welding 2 horizontal wells $0.09022
Cost of welding 5 vertical wells 0.11470

Cost of welding all wells $0.20492

This cost is based on actual welding time only and must be increased due to the time required to cut the pieces, peen over the ends of the pipe, fit the pieces together and test the welds for leaks. This is estimated to be 10 times the cost of welding which brings the cost of the welded thermometer wells to:
Welding $0.20492
Making up 2.04920

Total cost .... $2.25512 or $2.26

Summary of Costs

	Standard Practice	Welded Construction	Actual Saving	Saving in % of St'd Practice
Cost of assembling the steel frame	$ 34.27	$ 7.92	$26.35	76.8%
Cost of assembling the ammonia pipes	69.70	50.87	18.83	27.0%
Cost of thermometer wells	10.20	2.26	5.94	72.5%
Totals	$114.17	$61.05	$51.12	45.6%
Cost of auxiliary equipment.				
Cost of the gas fired forge	$ 5.30	$ 3.30	$ 2.00	37.7%
Cost of the bending irons	none	1.92	none	none
Cost of the tongs	2.00	1.71	0.68	34.0%

Fig. 14. Refrigeration plant completed.

The gas-fired forge and the tongs would not be needed for the installation of the pipes by means of standard practice but are listed for comparison with the welded construction method. The auxiliary equipment listed under welded construction were in good condition when the installation was completed and could have been moved to the next job, if another installation was to have been made, and the cost of their construction on the next job would not be necessary.

Conclusion—It is evident from this cost comparison that the gross saving accruing from the use of welded construction would be very large. Of course the steel structure which was installed in this case would not be necessary in connection with ordinary refrigeration plants and for that reason this installation was more or less a special case. However the ammonia piping system is the same as that used in standard refrigeration systems and in this connection a saving estimated to be in excess of one fourth of the installation cost was effected. And the neat appearance of the bends and welds enhances the value of the entire installation.

Advantages of Welded Construction—1, The ammonia pipes remain perfectly gas tight with little inspection or care; 2, The points at which leaks could occur are reduced to a minimum; 3, The easy bends and welds give the whole plant a rather pleasing appearance; 4, After several months no ammonia has been lost from the system showing that it is still perfectly tight; 5, Bending the pipes and welding them into place simplifies the installation; 6, The piping is a single unit; 7, Repairs can be made easily by simply pumping the ammonia out of the place to be repaired and cutting out the defective piping and bending and welding a new piece of pipe into place; 8, Additions to the ammonia pipes can be easily made; 9, The welded steel structure is quite rigid without the aid of triangular bracing.

Chapter XI—Special-Duty Steel-Plate Fan

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Subject Matter: For conveying away the product of attrition mills and heavy-duty cutters manufactured by a company, centrifugal fans about 2 or 3 feet in diameter were required. If purchased fans were used, they were subject to the disadvantages that deliveries were uncertain, in many cases the air pressure was too low unless the fans were belt-driven at higher speed and the cast iron fan blades were designed for air only, and being rough, would choke up with material. By building their own fans with arc welded construction, the company not only overcame these disadvantages, but lowered costs as well. The average saving by using the welded fan was 55 per cent.

The object of this article is to present the advantages of an arc welded fabrication as it concerns the development, design and manufacture of a new product by a small manufacturer. The new product was a special-duty steel-plate fan for which the company with which I am connected had a limited sales outlet. This standard type of fan had formerly been bought outside and served as a secondary unit to service our primary machines.

An effort will be made to show that, due to welded construction, the necessary development stage of this special fan could be made at a low cost. A low-cost of development is a positive necessity if a small company is to compete successfully in a field dominated by large manufacturers. It is assumed that the small manufacturer has a relatively limited sales outlet and that his manufacturing facilities are not subject to mass production methods.

It will also show that, because of the welded construction, this fan, (See Fig. 1), could be manufactured economically and, thus, make possible the profitable sale of this fan in a competitive market.

The fan under consideration is designed for handling air in combination with heavy concentrations of finely ground material. The power applied to the fans varies from 2 to 10 horsepower, and the pipe size of the inlet and outlet ducts range from 6-inches to 8-inches in diameter. Fig. 2 and Fig. 3, show the various sizes of both the motor-driven and belt-driven fans.

In order to sell a complete installation, small companies are often forced to sell secondary equipment which they do not manufacture. This secondary equipment must operate along with the primary units, of the small manufacturer's own make, and upon the efficient and trouble-free operation of the secondary units will hinge the success or failure of the entire installation. In order to meet competition, these secondary units must be bought and sold at a profit that is small in proportion to the responsibility entailed for their successful operation.

To meet some special applications, standard types of machines must

Fig. 1. Steel plate fan.

sometimes be run under conditions unfavorable to their efficient operation. It happens also that the size, capacity and driving arrangement of some standard secondary units are very much out of proportion to what would be the actual requirements of a machine built especially for the work.

The small manufacturer will find it nearly impossible, economically, to buy tailor-built machines to service the large units of his installations, assuming a relatively small number of large units are to be sold.

As a consequence of this condition, oft, times the builder will be forced to buy standard secondary units outside and absorb, as best he can, the higher cost and pass along to his good customer an inefficient operating machine.

The company with which I am connected was up against exactly this condition in the installations of their attrition mills and special heavy-duty cutters

The fans that we were using to convey the processed material away from these units were of an outside manufacturer's standard make and were not designed specifically for the purpose for which we were using them. As a consequence, the operation of these fans was oft, times quite unsatisfactory with the result that the operations of the entire installation would be condemned

The fans we had been buying were primarily designed for handling air whereas the fans, to suit our requirements, should have been designed for handling heavy concentrations of finely ground processed material in conjunction with air. The fans were of cast iron construction, and, while this material has very desirable wearing properties, it, nevertheless, has very

undesirable performance characteristics when the fan is new. The rough inside surface of the spiral casing collects the finely ground material and builds up until the fan is completely choked. This rough surface condition will wear off after several months of operation, but, nevertheless, it would be very desirable to have maximum capacity and efficiency for the new installation.

The pressure characteristics of these fans were such as to make it impossible to directly connect the fan impeller to the spindle of a 1760 revolutions per minute motor. To develop the required pressure, a speed-up V-drive would be required with a corresponding increase in price as a shaft and bearings would be required for the fan. The V-belt drive and supporting base for the fan and motor would also further increase this price.

Fully realizing the design shortcomings and expensive drive arrangement of these standard fans, a decision was made to design and manufacture an experimental fan.
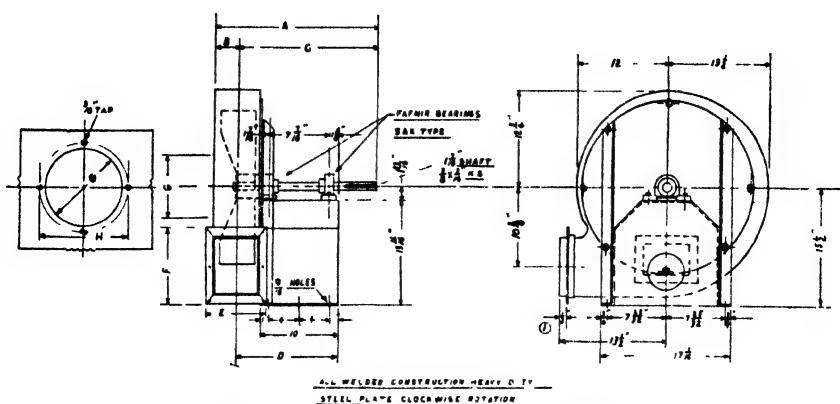
Fig. 2. Fan and bearing support assembly.

Development of Fan—The decision to manufacture this fan was made possible by the fact that we could fabricate it with the electric arc. Had it been necessary to make patterns, obtain necessary steel castings and machine castings, it would have been economically impossible for us to have produced this fan or others like it in a competitive market. A preliminary survey showed that, by using plates and the electric arc, we could manufacture the fans with absolutely no other machining work than that required to bore and key seat the fabricated fan impeller.

The experimental fan was engineered to suit exactly the air requirements for one of our jobs. The entire details of this experimental fan were worked out on one drawing size 16-inch x 21-inch. Of course, considerable experience with this type of fan was necessary before this design could be made.

An experimental fan was actually manufactured in our shop for a cost of $55. The cost covers material, labor and 180% for shop overhead. No breakdown of this cost will be given as, for a single unit of this type, any breakdown in cost would be meaningless.

Two slight revisions were found to be necessary from the results of field tests. It was found that the fan impeller needed reinforcing to withstand the impact of heavy particles entering along with the air stream. As this

fan was now 100% under our control, this defect could be remedied by simply revising the drawing and recalling the prints from our shop. This experimental fan was tested under field conditions in which an outside manufacturer's standard fan had been rendering very poor service.

Our fan clearly demonstrated its superiority over the standard fan and convinced us that the design of the fan was sound. The smooth surface of the steel sheets on the inside of the fan was so self-cleaning to the finely ground product that we found we could reduce the horsepower applied to the fans by approximately 25% less than for the cast iron fans and still obtain satisfactory operation.

With the conclusion of these tests on our experimental steel plate fan, it could be safely said that our development work was practically completed. The experimental fan was ready for test approximately one week after the tracings for the fan had been completed. The tests were completed in approximately two months on an actual field job. The entire development cost on this fan would not be over $300.

Design of Fan—The cost of the experimental fan had been considerably lower than the cost of the comparable cast iron fan obtained from an outside manufacturer. The results of the tests were also so successful that we decided to manufacture a line of fans to suit our particular requirements. These fans would be designed for direct motor drive, but, at the same time, provision would be made for belt-drive so that the unusual operating condition sometimes encountered could be handled.

Table I—Bill of Material

Heavy Duty Fan for No. 3 Products Collecting System
To Be Used With 7½ H.P. Motor, 1750 R.P.M.

No. Pcs.	Description
1	Fan Side and Motor Support—Use Arrangement No. 3 for Mounting Motor Weld 5/16" Plate 21¼" Dia.—Cut from Fan Housing to Fan Side 4 ½" × 1¾" Machine Bolts with Cut Washers
1	Fan Housing—See Order (Clockwise as Shown) For No. 3 Pneumatic System (Counter Clockwise Opposite) 4 ⅜" Studs ¾" Long—Double Refined Iron 4 ⅜" Wing Nuts 4 ⅜" × ⅝" Cap Bolts with Lock Washers 4 ⅜" × ½" Cap Bolts with Lock Washers
1	Felt Gasket 23" O.D. × 21¼" I.D. × 1/16" Thick
1	Felt Gasket 8" × 6" to 6" × 4" × 1/16" Thick
1	Fan Impeller for No. 3 Outfit, Bore 1¼", K.S. ¼" × ⅛" and S.S. (See Order for 20" Dia. or 21" Dia. Impeller) 1 Piece C.T.S. 2 15/16" Dia. × 3⅛" Long 2 ⅜" Headless Set Screws
1	7½ H.P., 1750 Open Type Sleeve Bearing Motor—Frame No. 284 (See Order for Current Characteristics)
1	Allen-Bradley No. 709 Magnetic Starter Separate Push Button for Above Motor

Table II—Bill of Material

Heavy Duty Fan—Belt Driven
For No. 1 Pneumatic Products Collecting System

No. Pcs.	Description
1	Fan Side and Bearing Support
	Weld 3/16" Plate 21¼" Dia.—Cut from Fan Housing to Fan Side
	4 ½" Machine Bolts 1½" Long with Cut Washers—Nuts Welded to Underside of Support
1	Fan Housing—See Order (Clockwise as Shown)
	For No. 1 Pneumatic System (Counterclockwise Opposite)
	4 ⅜" Studs ¾" Long
	4 ⅜" Wing Nuts
	4 ⅜" × ⅝" Cap Bolts and Lock Washers
	4 ⅜" × ½" Cap Bolts and Lock Washers
1	Felt Gasket 23" O.D. × 21¼" I.D. × 1/16" Thick
1	Felt Gasket 8" × 6" to 6" × 4" × 1/16" Thick
1	20" Fan Impeller for No. 1 Outfit, Bore 1 7/16", K.S. ⅜" × 3/16" and S.S. as Per Dwg.—Except Bore
	1 Piece C.T.S. 2 15/16" × 2¼" Long
	2 ⅜" Headless Set Screws
1	Fan Shaft—1 7/16" Dia. × 18⅛" Long—K.S. One End ⅜" × 3/16" × 3⅛" and K.S. Other End ⅜" × 3/16" × 4" Long
1	Straight Key ⅜" × ⅜" × 3" Long
1	Straight Key ⅜" × ⅜" × 3¾" Long
2	1 7/16" Fafnir Bearings—Single Pillow Blocks, Light Series—SAK Type
2	No. 4 Taper Pins (Bearing to Bearing Support)

Table III—Bill of Material

Heavy Duty Fan—Belt Driven
Nos. 2, 3 & 4 Pneumatic Products Collecting System

No. Pcs.	Description
1	Fan Side and Bearing Support
	Weld 3/16" Plate 21¼" Dia--Cut from Fan Housing to Fan Side
	4 ½" Machine Bolts 1½" Long with Cut Washers—Nuts Welded to Underside of Support
1	Fan Housing—See Order (Clockwise as Shown)
	For No. 2 Outfit (Counterclockwise Opposite)
	4 ⅜" Studs ¾" Long—Double Refined Iron
	4 ⅜" Wing Nuts
	4 ⅜" × ⅝" Cap Bolts and Lock Washers
	4 ⅜" × ½" Cap Bolts and Lock Washers
1	Felt Gasket 23" O.D. × 21¼" I.D. × 1/16" Thick
1	Felt Gasket 8" × 6" to 6" × 4" × 1/16" Thick
1	20" Fan Impeller for No. 2 Outfit—Bore 1 7/16"—K.S. ⅜" × 3/16" × S.S. as Per Dwg.—Except Bore
	1 Piece 2 15/16" Dia. 3⅛" Long
	2 ⅜" Set Screws
1	Fan Shaft—1 7/16" Dia. × 18⅛" Long—K.S. One End ⅜" × 3/16" × 3⅛" and K.S. Other End ⅜" × 3/16" × 4" Long
2	1 7/16" Fafnir Bearings—Single Pillow Blocks, Light Series—SAK Type
1	Straight Key ⅜" × ⅜" × 3" Long
1	Straight Key ⅜" × ⅜" × 3¾" Long
2	No. 4 Taper Pins (Bearing to Bearing Support)

Table IV—Bill of Material

Stock Parts for Pneumatic System Fans

No. Pcs.	Description
6	Fan Sides and Motor Supports (Do Not Provide Holes for Motor Attachment) (Used on Nos. 1, 2 and 3 Motor Driven Fans)
6	Fan Housings (3 Clockwise, 3 Counterclockwise) 6" Wide (For Use on Nos. 2 and 3 Motor Driven Fans and Nos. 2, 3 and 4 Belt Driven Fans)
4	Fan Housings (2 Clockwise, 2 Counterclockwise) 4" Wide (For Use on No. 1 Motor Driven and No. 1 Belt Driven Fans)
4	Fan Sides and Bearing Supports (For Use on Nos. 1, 2, 3 and 4 Belt Driven Fans)
4	Fan Shafts, 1 7/16" Dia. × 18 1/8" Long, K.S. 4 Straight Keys, 3/8" × 3/8" × 3 3/4" Long 4 Straight Keys, 3/8" × 3/8" × 3" Long (For Use on Nos. 1, 2, 3 and 4 Belt Driven Fans)
4	21" Fan Impellets for No. 1 Pneumatic System—Bore 1" (1 Pc. 2 15/16" Dia. C.T.S. 2 1/4" Long) (Use on No. 1 Motor Driven Fan and No. 1 Belt Driven Fan)
6	21" Fan Impellers for Nos. 2 and 3 Pneumatic Systems Bore 1 1/8" (1 Pc. 2 15/16" Dia. C.T.S. 3 1/8" Long) (Use on Nos. 2 and 3 Motor Driven Fans and Nos. 2, 3 and 4 Belt Driven Fans)
8	1 7/16" Fafnir SAK Pillow Blocks

Table V—Bill of Material

Heavy Duty Fan for No. 1 Products Collecting System To Be Used With 3 H.P. Motor, 1750 R.P.M.

No. Pcs.	Description
1	Fan Side and Motor Support—Use Arrangement No. 1 for Mounting Motor Weld 3/16" Plate 21 1/4" Dia.—Cut from Fan Housing to Fan Support 2 2" × 13" × 3/4" Bars—Weld to Motor Support 2 2" × 12" × 3/4" Bars—Weld to Above Bars 4 3/8" × 1 1/4" Cap Bolts with Cut Washers
1	Fan Housing—See Order (Clockwise as Shown) For No. 1 Pneumatic System (Counterclockwise Opposite) 4 3/8" Studs 3/4" Long 4 3/8" Wing Nuts 4 3/8" × 5/8" Cap Bolts and Lock Washers 4 3/8" × 1/2" Cap Bolts and Lock Washers
1	Felt Gasket 23" O.D. × 21 1/4" I.D. × 1/16" Thick
1	Felt Gasket 8" × 6" to 6" × 4" × 1/16"
1	Fan Impeller for No. 1 Outfit, Bore 1", K.S. 1/4" × 1/8" and S.S. (See Order for 20" Dia. or 21" Dia. Impeller) 1 Piece C.T.S.—2 15/16" Dia. × 2 1/4" Long
2	3/8" Headless Set Screws
1	3 H.P. 1750 R.P.M. Open Type Sleeve Bearing Motor See Order for Current and Voltage—Frame No. 225
1	Allen-Bradley 609, Size 1, Open Type Starter for Above Motor

Table VI—Bill of Material

Heavy Duty Fan for No. 2 Products Collecting System
To Be Used With 5 H.P. Motor, 1750 R.P.M.—Frame No. 254

No. Pcs.	Description
1	Fan Side and Motor Support—Use Arrangement No. 2 for Mounting Motor
	Weld 3/16" Plate 21¼" Dia.—Cut from Fan Housing to Fan Side
	2 2½" × 13" × ¾" Bars—Weld to Motor Support
	4 ½" × 1¼" Cap Bolts with Cut Washers
1	Fan Housing—See Order (Clockwise as Shown)
	For No. 2 Pneumatic System (Counterclockwise Opposite)
	4 ⅜" Studs ¾" Long—Double Refined Iron
	4 ⅜" Wing Nuts
	4 ⅜" × ⅝" Cap Bolts and Lock Washers
	4 ⅜" × ½" Cap Bolts and Lock Washers
1	Felt Gasket 23" O.D. × 21¼" I.D. × 1/16" Thick
1	Felt Gasket 8" × 6" to 6" × 4" × 1/16" Thick
1	Fan Impeller for No. 2 Outfit, Bore 1⅛", K.S. ¼" × ⅛" and S.S.
	(See Order for 20" Dia. or 21" Dia. Impeller)
	1 Piece C.T.S.—2 15/16" Dia. × 3⅛" Long
	2 ⅜" Headless Set Screws
1	5 H.P., 1750 R.P.M. Open Type Sleeve Bearing Motor Frame No. 254 (See Order for Current Characteristics)
1	Allen-Bradley 609, Size 1, Open Type Starter for Above Motor

The bills of materials for these fans are given in the accompanying tables. These bills of material list seven different types and sizes of fans and cover 95 per cent of the fan requirements for our primary machine. By close inspection of the bill of materials, you will note some of the parts for one size of fan will fit all of the other fans, and, by keeping in stock the eight parts shown on bill of material headed "Stock Parts for Pneumatic Systems," Table IV, we were able to carry in stock for immediate shipment all of the seven different types of fans.

A small manufacturer will find an arrangement of this sort a prime necessity if his market conditions permit the sale of only a small number of the different types of units.

To show the extreme simplicity of the design of this fan, as made possible by the electric arc, a description of the design of one representative size of fan will be given. This fan is shown in Fig. 1.

The bill of material is Table I and is for a heavy-duty fan for No. 3 products-collecting system to be used with 7½ horsepower motor, 1750 revolutions per minute.

Piece No. 1—Fan side and motor support—arrangement No. 3 for mounting motor. The 12-gauge black iron piece 23-inch diameter and the 3/16-inch black iron plate (cut from fan housing) are cut out with the torch and plug welded together with eight—9/16-inch plug welds. Plug welds are used to join these two pieces together so as to minimize distortion and to maintain a clear edge in the 3/16-inch plate piece for bolting. The 7/16-inch holes are punched in the 12-gauge black iron fan side. These bolts are used to hold the fan case to the fan side in the final assembly and to act as a jig for holding the 1½-inch × 1½-inch × 3/16-inch angles of the fan side for aligning and welding.
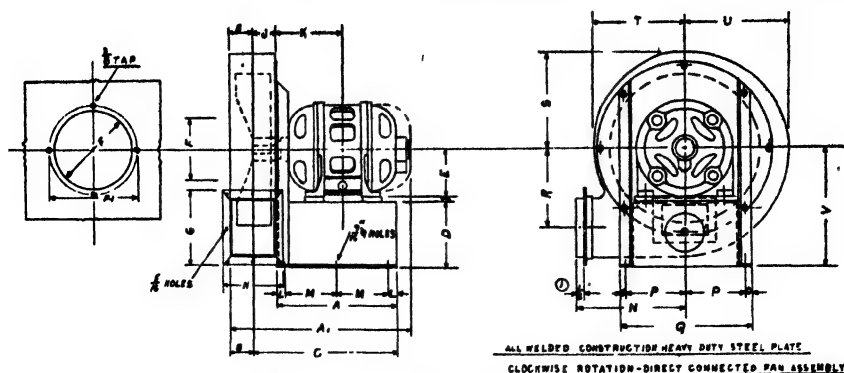
Fig. 3. Fan and motor assembly.

The ¼-inch plate is bent on the break and welded to the angles that have been bolted and welded to the 12-gauge black iron fan side. This entire assembly is made without the use of a jig, and all the welds can be made vertical as the piece is small and can be easily turned by hand to the correct welding position. No machine work is required on this piece as the method of welding and the size of the plates are such that no distortion occurs. The fan side is stocked with the motor support plain and by adding the necessary filler pieces, this assembly serves for three sizes of fans.

Piece No. 2 on the bill of material is the fan housing for the No. 2 pneumatic system. The fan sides of 3/16-inch and 12-gauge black iron are cut out with the radiograph. The one side is made 3/16-inch so as to keep distortion down and to offer sufficient grip for the ⅜-inch cap bolts. The 10-gauge black iron scroll sheet is sheared and bent on the break to the correct shape, tack welded to the side plates and then continuously welded with ⅛-inch fillet welds. This assembly is welded without the use of a jig as the peculiar shape of the scroll sheet makes a flat and upright surface for attaching the side plates. This piece is small enough so that it can be positioned by hand for efficient welding. This fan side serves five different sizes of fans.

Piece No. 3—Fan impeller for No. 3 outfit 21-inch diameter, bore 1¼-inch, keyseat ¼-inch × ⅛-inch. This fan impeller as supplied in competitive fans has either a cast steel hub with angle irons cast in the steel and extended to support the fan blades or else the hub and arms are made in one steel casting. It was feared that because of the high radial stresses existing in the welds at the point where the blades are welded to the hub and because of the unknown tangential stress caused by impact of the blades with the product in the entering air stream that trouble might be had with an all-welded impeller. The shop was cautioned as to this condition and has given us very good welds. The tip speeds on some of the belt-driven units are as high as 12,500-feet per minute; radial stress at junction of hub and blade about 5,000-pounds per square inch and considerable tangential impact stress at this point also, but to date not one fan impeller has failed.

The fan blades on these impellers are sheared to size and after being welded to the hub are finally ground to the correct diameter. The finished impeller is given a good static balance and excellent running balance is secured. The homogeneous structure of steel plates makes it possible to get a good running balance from these static balanced impellers.

The blades for these fan impellers are sheared from waste pieces of

steel plates and actually have no material cost. The hub is made from cut-off ends of $2^{15}/_{16}$-inch commercial-turned low carbon steel.

The fan impellers are stocked 21-inch diameter, not bored or ground to diameter, and are removed from stock on receipt of a definite order, bored, keyseated, ground to diameter, and balanced to suit the order conditions.

This fan impeller as stocked can be ground to diameter and bored to suit five different sizes of fans.

The remaining parts are the driving motor, starter, necessary bolts and felt gaskets.

From the above list of parts, it will be evident that there are only three parts for the fan that must be fabricated in our shops.

As stated once before, no machine work is required on this fan other than required to bore and keyseat the fan impeller.

Comparative Cost of Fans

Our steel plate fan complete with fan impeller mounted on motor spindle and motor mounted on side of fan.		Purchased cast iron fan with motor and necessary V-belt drive and fabricated base to connect fan and motor.	
#1. System—Direct motor drive steel plate fan	$ 55.00	#1. System belt driven cast iron fan—Fan No. 23	$ 72.50
3-H.P., 1760 motor, 3P-60C-220V.—Open Sleeve Bearing	49.50	5-H.P., 1760 motor, 3P-60C-220V. Open Sleeve Bearing..	60.30
		6.4 P. dia. 2-groove B-sheave	7.28
		5.6 P. dia. 2-groove B-sheave	6.72
		2 B68 belts	2.57
		Base plate	25.00
Total	$104.50	Total	$174.37
#2. System Direct Motor Drive Steel Plate Fan	$ 55.00	#2. System belt-driven cast iron fan—Fan No. 24	$ 91.50
5-H.P., 1760 motor, 3P-60C-220V. Open Sleeve Bearing..	60.30	7½-H.P., 1760 Motor, 3P-60C-220V. Open Sleeve Bearings	79.30
		6.4 P. dia. 3 G.B. Sheave	8.71
		5.6 P. dia. 3 G.B. Sheave	8.12
		3 B68 belts	3.86
		Base plate	30.00
Total	$115.30	Total	$221.49
#3. System Direct Motor Drive Steel Plate Fan	$ 55.00	#3. System belt-driven cast iron fan—Fan 24-A	$ 91.50
7½-H.P., 1760 Motor, 3P-60C-220V. Open Sleeve Bearing	79.30	10-H.P., 1760 Motor, 3P-60C-220V. Open Sleeve Bearing..	101.00
		6.4 P. dia. 4 G.B. Sheave	10.10
		5.6 P. dia. 4 G.B. Sheave	9.45
		4 B68 belts	5.15
		Base plate	35.00
Total	$134.30	Total	$252.20
#4. System Direct Motor Drive No. 3 Steel Plate Fan	$ 65.00	#4. System belt-driven cast iron fan—Fan No. 25	$115.00
10-H.P., 1760 Motor, 3P-60C-220V. Open Sleeve Bearing..	101.00	15-H.P., 1760 motor, 3P-60C-220V. Open Sleeve Bearing....	121.00
		6.4 P. dia. 5 G.B. Sheave	11.50
		5.6 P. dia. 5 G.B. Sheave	10.86
		5 B68 belts	6.43
		Base plate	40.00
Total	$166.00	Total	$304.79

The average net saving for the operating unit per complete installation would be $108.18. The cost of the steel plate fan per installation is but 54 per cent of the cost of an equivalent standard cast iron fan for the same installation. The average net saving for the fan units only would be $35.12. The cost of the steel plate fan is but 62 per cent of the cost of an equivalent standard cast iron fan.

The cost of a complete operating unit, however, is the cost that counts in a competive market and on this basis the net saving per installation would be as noted above, $108.18, and the average horsepower saving would be 3.1.

On the basis of 50 installations per year, this saving would amount to $5,409.00. The horsepower saving would amount to 155 horsepower or, on the basis of 10 hours a day per five-day week, a total of 403,000 kilowatt hours would be saved per year. Of course, this monetary saving is passed along to our customers, but, nevertheless, we benefit directly in that we are able to place a lower bid on an installation, and thus, better our chances of securing additional business.

The saving in horsepower will permit our customer to process his product more economically and will help to secure his favorable reaction to the proposed installation. The company benefits directly in that the work of fabricating this fan is now in our own shop and would help to reduce the shop overhead expense.

The company benefits also in having direct control over the delivery time of the manufactured product. Equipment bought outside must frequently be waited for with the result that shop and shipping schedules are delayed and valuable equipment is held up for want of secondary equipment of relatively minor importance.

Results Obtained by Arc Welding the Steel Plate Fan—As stated before, the ability to arc weld this fan from steel plates made possible the manufacture of this fan by the company with which I am connected.

The benefits accruing from the manufacturing of this fan were as follows:

The company was able to convert an unprofitable secondary unit of its business into a profitable unit of business. This conversion resulted in an improved performance of the secondary unit with the result that the operation of the primary units was also materially improved.

Our customers were able to buy their equipment more economically and to run it at lower power requirements.

In a small way, this saving will enable them to lower the cost of their product with the result that mankind in general will be able to benefit by being able to supply their wants more economically and, thus, in greater abundance.

Chapter XII—Parts for a Receiving-Switching-Transmitting Unit

By Adam Drenkard, Jr.,

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Adam Drenkard, Jr.

Subject Matter: How arc welding simplified the problem of constructing a receiving-switching-transmitting unit for a telegraph reperforator switching installation. In the original model of the four-position receiving table, the screw and gusset plate method of assembly was used in order to facilitate any necessary change in shelf height; but, as a result of steel shortages arc welding became essential—almost 25,000 pounds of steel being saved in the construction of the equipment described in this paper alone. Proportionate cost savings are analyzed in detail, indicating a net overall of 23.8%.

The telegraph business is concerned primarily with the transmission, in record form, of messages from a large number of originating points to an equally large number of receiving points. Because of the universal service it provides, reaching into virtually every town and hamlet in the nation, it can be operated economically only through the medium of central relay offices. Each of these relay offices has direct wires to a number of originating points and receiving points in its section of the country and also direct wires to one or more other relay offices. In this respect the handling of traffic is similar to that employed by the telephone companies with their multiplicity of central offices. It is distinguished from telephone service however in that over 95% of the business handled at telegraph relay offices is received and transmitted over printing telegraph circuits.

Under the standard procedure at relay offices not equipped with the recently developed reperforator switching system a considerable amount of manual work is involved. Reception at a relay office requires the services of a receiving operator who checks the message for possible errors, times it, records its sequence number and then releases it. The telegram is then manually, or mechanically by means of belt conveyors, carried to a central distributing center. Here it is routed, again manually, to the circuit over which it is to be retransmitted. It is then carried, again manually or mechanically, to the transmitting position where the services of a transmitting operator are required.

In addition to the operators and distributing and routing clerks already mentioned, an adequate staff of supervisory forces must be provided to insure the expeditious handling of the messages since they must be delivered at their destinations within a very few minutes after being filed at the originating point.

The development of a reperforator switching system was undertaken with the intention of eliminating as many of the manual operations as possible and replacing them with a single, accurate, high speed switching operation.

In the reperforator switching system means have been provided whereby distant stations may transmit into the relay office at their own convenience at any time without any delay in the reception of the message. A switchboard or switching turret has also been provided through which the received messages may be distributed at high speed to the transmitting terminals of the outgoing circuit. At the transmitting terminals all telegrams for each circuit are accumulated in a storage device from which the messages are transmitted as fast as the line can accept them. By this system the manual operations have been reduced to one handling, namely the routing of the incoming message through the switching turret.

The three major elements involved in the passage of a message through a relay office are the four-position receiving table, the 256 jack switching turret and the four-position sending storage table. These three items together comprise the reperforator switching unit which is described in this paper.
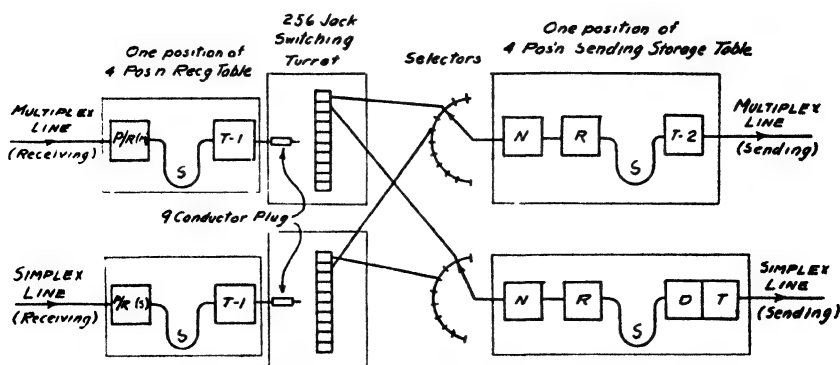
Fig. 1. The major items involved. Code: P/R(M), multiplex printer perforator, 65 words per minute; P/R(S), simplex printer perforator, 65 words per minute; S, tape storage loop; T-1, tape transmitter, 125 words per minute; T-2, tape transmitter, 65 words per minute; N, automatic message sequence numbering machine; R, reperforator, 125 words per minute; DT, distributor-transmitter, 65 words per minute.

Development—In 1933 the first practical attempt by the Western Union was made to handle traffic by means of automatic reperforation. The telegrams were received in the form of a perforated tape. Operators read the coded perforations in the tape, routed the messages to the proper outgoing circuit and then the short length of tape bearing the perforated message was physically transported to the transmitting position. This system was soon found to have no practical advantage over existing methods because of the difficulty of accurately reading the perforations and of transporting the short pieces of tape. There was also a possibility of delayed handling of the messages.

In 1934 an improved version of the reperforator switching method was tested in a small trial installation at Fort Worth, Texas. In this system a printing perforator was substituted for the perforator used for receiving in the original plan. This unit printed the message on one tape and perforated the message on another tape. The operator was thus enabled to easily read the message destination on the printed tape.

The perforated tape was then fed through an automatic transmitter associated with a switching plug by means of which the message was routed to an outgoing circuit connection. This connection was not the outgoing circuit itself but an intra-office circuit which cleared the transmitter at the receiving position and transferred the message to a storage device at the outgoing circuit. The intra-office circuit operated at 90 words per minute as compared to the 65-words per minute speed of the receiving circuit, thus absorbing the slack caused by any delay in switching. Transmission on the outgoing circuit started immediately or as soon as the line was cleared of any business already stored from some other circuit.

After some further refinements, chief of which was the development of the printer-perforator, a larger trial installation was made at Richmond, Virginia. The printer-perforator is a machine which simultaneously prints the message and punches the code perforations on the same tape, thus simplifying the routing procedure.

A new high-speed perforator was also developed for use at the outgoing transmitters. These perforators were capable of operating at 125 words per minute and the intra-office transmission was thus stepped up to almost double the circuit receiving and sending speed. Thus was avoided the congestion which occasionally had occurred in the previous system due either to the gradual accumulation of time consumed in switching or to "waiting time" caused when a needed outgoing circuit was pre-empted by another transmitter.

The above brief summary gives a general description of the fundamental elements required. Numerous auxiliary devices are also employed but since they are beyond the scope and purpose of this paper no attempt will be made to describe them.

Fig. 1 is a greatly simplified drawing showing the relationship between the various major items involved in a reperforator switching system installation. One or more jacks appear in each switching turret for every circuit being relayed at the reperforator switching office. The jacks for each office in all turrets are multiplied together so that it is possible for any receiving position to route a message to any transmitting position. Schematic connections between only two turrets and sets of equipment are shown.

Operation of the Richmond installation provided an opportunity for an exhaustive study to determine the optimum placement of the many individual items of equipment at the operating positions, commensurate with the most efficient and speedy traffic handling.

Thereupon plans were laid for the final design and standardization of the various operating equipment assemblies so that use of the new system could be extended to most of the large cities of the country. Design work was begun early in 1940 and completed late in the same year.

In the meantime it had been decided to make the first installation of the standardized equipment at the Atlanta, Georgia relay office. Immediately upon completion of design work on each item of equipment it was rushed into production. As a result it was possible to begin installation work at Atlanta long before the design of all items had been fully completed. The Atlanta office was "cut-over" to complete reperforator switching operation late in the summer of 1941.

Fig. 2 is a view of a switching aisle in the Atlanta office showing the relationship between the four-position receiving table and the 256 jack switching turret. Fig. 3 shows a storage aisle consisting of rows of four-position sending storage tables located directly behind the switching aisle.
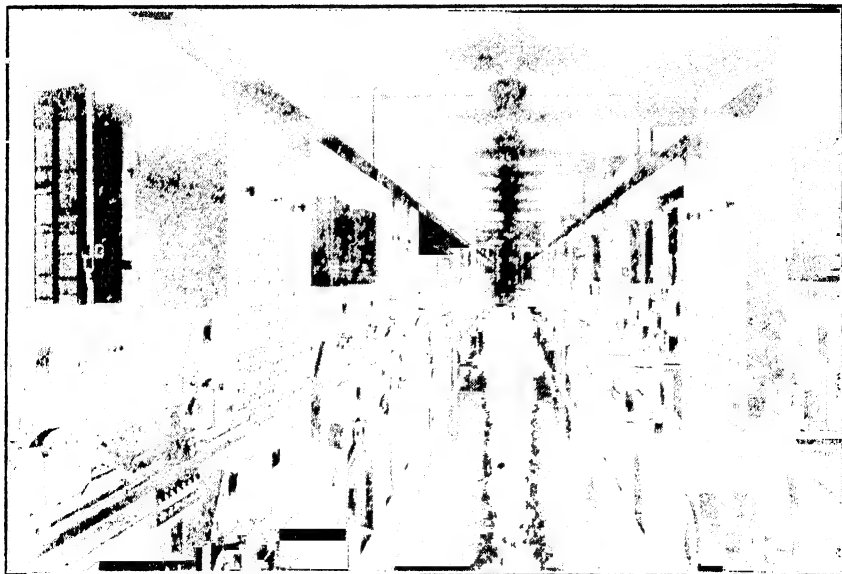
Fig. 2. Switching aisle.

The Atlanta installation has now been in operation for over eight months and is the most modern telegraph relay office in the world. Some of the salient features of improved operation are listed below.

1. Studies have shown that a reduction of 75 per cent has been achieved in the time required to clear a message through the office as compared with the old method of operation.

2. There has been a gain in accuracy due to the elimination of manual reperforation and transmission of each message.

3. An increase in the capacity of inter-city circuits of over 25 per cent has been attained because transmitters function continuously as long as there are telegrams to be transmitted. This was impossible under manual operation.

4. Physical and mental effort required of the operating personnel has been greatly reduced.

5. A considerable reduction has been effected in the space requirements for the central relay office equipment because of the concentration of the machines on the newly designed tables and also because the mechanical equipment formerly required for the transportation of messages about the office has been eliminated.

Design—When preliminary design work was begun on the reperforator switching system equipment it was necessary to obtain experimental models of the units so that laboratory setups could be made. This was done primarily in order to afford an opportunity for the various operating and development departments to suggest changes or additions which would meet their requirements.

In the original model of the four-position receiving table the screw and gusset plate method of assembly was used. This was done .. order to

facilitate any change in shelf height and size necessary to meet the requirements of the various departments concerned. Incidentally this model gave a clear indication of the impossibility of meeting the limits set up for maximum floor space per unit with gusseted construction because the gusset plates prevented proper placement and operation of the telegraph equipment.

The cost of the model also provided a basis for comparison between the cost of arc welded construction and gusseted and, when adjusted for quantity production, checked very well with the figures calculated in the cost analyses given herewith.

In designing the receiving and sending storage tables one of the primary considerations was rigidity of construction. This quality was especially important because of the fact that most of the equipment on these tables is semi-portable and must be readily removable for replacement in the event of failure.

Each unit of equipment is fastened in place through the medium of a separate sub-base with male clips. Female clips on the various items engage the male clips on the sub-base in order to establish the electrical connections required. When a machine is inserted into a sub-base considerable pressure must be exerted in a horizontal direction in order to fully engage the spring clips—32 in number in the case of the printer-perforator Only with arc welded construction would the required rigidity be attained since no bolted joint can be made as strong as the parent metal, whereas with arc welding it can be made stronger than the parent metal

In the switching turret, a somewhat similar condition exists Since intra-office transmission is on a nine wire basis (multiplex plus control leads) nine conductors are required per circuit As a result the plugs through which the routing connection are established are decidedly larger than the conventional telephone, radio or telegraph plug The repeated shocks incident to the heavy thrust exerted when plugging up and pushing home several thousand connections per day per turret through so large a plug made arc welded construction the only alternative.

Appearance—Another prime requisite in the equipment design was the attainment of a neat orderly appearance when a large number of units is installed in a central office Therefore simplicity was the keynote and could be best obtained by arc welding The side supporting members of the receiving tables are butt welded to the square root cold drawn angle shelf frames and then ground smooth Thus two adjacent tables can be bolted together without any gap or slot between them. The square root angles forming the shelf supporting frames also serve as a protective edge for the plywood shelves and eliminate the necessity of providing the conventional aluminum shelf edging Without the use of arc welding it would be well nigh impossible to obtain the neat corners and the strong shelf edges which distinguish these tables.

Maintenance—Arc welded construction, in eliminating the unsightly gussets, screws, nuts etc. has also simplified the maintenance and cleaning problem. The smooth, uninterrupted surfaces of the present equipment have practically eliminated dust catching crevices and dark corners, thus cutting maintenance costs.

Saving in Critical War Materials—In addition to the saving in the vital metal aluminum mentioned above, a large saving in sheet steel is made possible because of the rigidity of construction obtainable with arc welding.

Fig. 3. Storage aisle.

Early in January, 1942, the office of production management, at a hearing in Washington at which the writer was one of the representatives of the Western Union, reviewed the request for a priority preference rating certificate covering all the material required to complete the 1942 reperforator switching program. This program contemplates the installation of partial reperforator switching systems in 18 cities and complete reperforator switching systems at Dallas and St. Louis. These installations were made necessary by the rapidly increasing demands for additional telegraph services by essential war industries and government agencies.

As a prerequisite to the granting of the certificate the company was asked to reduce its sheet steel requirements for the complete program by 25,000 pounds.

A net saving of over 30,000 pounds was made by redesigning the various structures involved. Almost 25,000 pounds was saved in the construction of the equipment described in this paper alone. The arc welded construction of these items made it possible to make these savings merely by substituting non-metallic sheets because it was not necessary to depend upon the strength of the metal sheets in order to obtain sufficient rigidity. This would not have been possible with gusseted construction.

Another saving in material by the use of arc welding is accomplished by the reduction in size of the various supporting members of the equipment. With the old gusseted method the minimum size of the shelf supporting members of tables was generally 1½-inches x 1½-inches x 3/16-inch in order to allow sufficient space for the bolts required to hold the gusset plates in position and also to attain rigidity. It will be seen by an inspection of the drawings included herewith that all shelf supporting angles have now been reduced to 1-inch x 1-inch x ⅛-inch in size, resulting in a substantial reduction in the quantity of steel required. This has been done with no reduction in strength or rigidity but rather an increase in these qualities.

Thus it may be seen that arc welding has contributed materially to the conservation of critical materials now so vital to the war effort.

Reduction of Floor Space Requirements and Operator Fatigue—When designing units of the type described, of which a large number are to be installed in a given office, it is highly important to keep to a minimum the floor area required by each unit. This is readily understandable.

Increase in floor area directly affects the rental costs. In addition there is a decided increase in operator fatigue. Each time a message is routed the operator must walk from a central location, usually in front of the turret, to the position at which the message is being received. She must then read the message destination and walk back to the turret to plug up the connection. An increase of an average of say two feet of walking per switched message may seem trivial but, when multiplied by as high as possibly a thousand per eight hour day, the increase in fatigue becomes quite considerable.

Fig. 4. Front view.

The photos show how compactly it has been possible to arrange the various machines on the tables It is obvious that if gusseted construction were used the space occupied by the gussets would be wasted and consequently the overall length of the units would have to be increased by as much as 25 per cent in each case.

A further saving in space requirements and critical material is directly attributable to arc welding. Before the development of the new type of tables the various resistors required were mounted in a position parallel to the mounting surface in the wiring cabinet This required a composition mounting block equipped with two phosphor-bronze mounting clips for each resistor. Four square inches of mounting space were thus used for each resistor.

Six rows of 1-inch x 1/8-inch steel strap are arc welded to the inside back of the wiring cabinet for the four-position receiving table. These

straps are drilled and tapped on 1 inch centers. Into each of these holes is screwed a long bolt which passes through the hollow center of a resistor, which is thus mounted vertically on the mounting surface. With this arrangement an area of only one square inch is necessary per resistor—a saving of 75 per cent. Furthermore there is a direct saving of the critical metal in the phosphor-bronze clips which are no longer required.

Four-Position Receiving Table—A total of 193-inches of short $\frac{3}{16}$-inch fillet welds, mostly 1-inch to $1\frac{1}{2}$-inches long were required for the arc welded assembly of the table framework and the cabinet. Ninety inches of butt and flush corner welds were required in order to obtain the smooth outside corners and joints.

Figs. 4 and 5 are front and side views of this type of table, partially equipped, taken at Atlanta during the course of installation work at that office.

Jack Switching Turret—In the manufacture of the basic framework of the 256 jack switching turret, the heavy side channels are supported by the arc welded cross members and channel top In assembling this framework 31-feet of $\frac{1}{4}$-inch fillet welds and 5-feet of butt welds were required.

The jacks were mounted on separate jack panels, two per panel. This method of assembly was necessary in order to facilitate the removal of jacks in the event of jack failure. Since the wiring at the back of the turrets is very congested due to the large number of wired connections required, removal of the jacks from the front was the only possibility. Hence, the

Fig. 5. (left). Side view. Fig. 6. (right). Front view of turret.

screw method of mounting the jack panels. The jack panel supports were also screwed in place in order to allow for adjustment in the lining up of the various small jack panels during the final assembly.

Here is illustrated a striking example of the high cost of screw construction as compared with the arc welding method. Reference to the cost analysis for the 256 jack switching turret will show that almost 60 per cent of the labor cost was attributable to the slotting, drilling and tapping of the jack panel supports. Had it been practicable from a maintenance standpoint to install a 256 jack panel instead of 128 two-jack panels, the large jack panel could well have been arc welded into place. This would have reduced the labor cost on this portion of the assembly at least 80 per cent
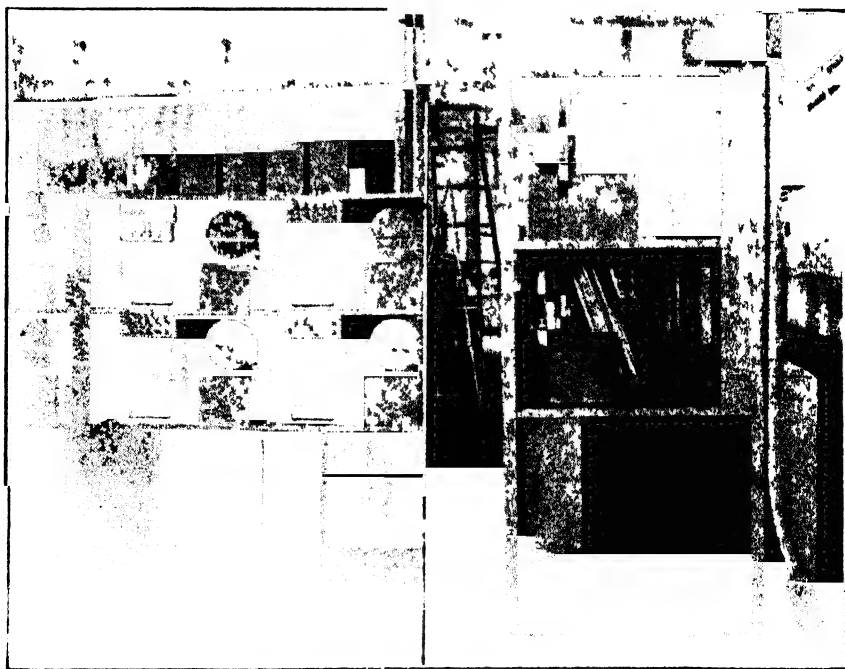
Fig. 7, (left). Front view of four-position sending storage table. Fig. 8, (right). Side view of four-position sending storage table.

Fig. 6 shows a front view of the turret, partially equipped with cords and with jacks and filler panels in place but without the lower front enclosing panel. Refer to Fig. 2 for a photo of completely equipped turrets. This photo also shows snap-up type seats fastened to the front of the turrets for the convenience of the switching operators. These seats have supported the weight of a 250-pound operator without any ill effect on the arc welded joints of the turret.

Four-Position Sending Storage Table—Two hundred and sixty-eight inches of short $\frac{3}{16}$-inch fillet welds were required for the assembly of the framework and the wiring cabinet. In addition to the fillet welds, 87-inches of butt and flush corner welds were required.

In the manufacture of one of the plywood shelves of this table, all re-

sistors are mounted on 1-inch x $\frac{1}{8}$-inch steel straps, arc welded in place and the entire framework is arc welded together.

The complete assembly of all the equipment on a four-position sending storage table illustrates the complete utilization of space made possible by arc welding.

Figs. 7 and 8 are front and side views of this type of table, partially equipped, taken during the course of installation work at Atlanta. The end panel of the table has been removed in the side view in order to show the large storage space provided for the storage of "sent" tape after the messages have been transmitted. The front view shows an open access door to this compartment. The side view also illustrates the smooth, clean appearance attained in a row of these tables, indicating the ease with which the equipment can be cleaned and maintained.

Proportionate Cost Saving in Percentage—Since the equipment described in this paper has never before been built in its present form I have elected to compare the costs using arc welded construction with the costs using gusseted construction as another reasonable method. I have selected the gusseted method as an alternate because such construction was for many years used in the design of tables and other equipment as hereinbefore noted. It should be borne in mind however that if gusseted construction were the only means available today the equipment would of necessity be much more cumbersome and would not as efficiently meet the requirements set forth in this paper.

On the following pages are found the cost analyses for arc welded construction of the three major items comprising a reperforator switching unit. Following the analysis for each unit is given a comparison between the arc welded cost and the cost using gusseted and bolted construction. The percentage saving with arc welded construction is also given.

The total cost figures for arc welded construction are the actual figures for the units manufactured for the Atlanta installation. The detailed figures for material are on the basis of prices prevailing at the time of manufacture.

The figures for welding costs for the two tables are based on a total of labor and electrode costs of \$.014 per inch for $\frac{3}{16}$-inch fillet welds and \$.019 per inch for butt and flush corner welds. These figures may seem rather high when compared with the figures quoted in the "Procedure Handbook of Arc Welding Design and Practice". They are, however, conservative in view of the multiplicity of short (1-inch and $1\frac{1}{2}$-inch) welds and the consequent high operator factor due to the fact that the arc is not in operation continuously.

The figures for the welding costs on the turrets are based on a total of labor and electrode costs of \$.08 per foot for $\frac{1}{4}$-inch fillet welds and \$.12 per foot for butt welds.

The "Overhead" item of 45 per cent is applied on the total cost of labor and material and includes layout, shop, purchasing and administrative costs.

In order to compare the costs by the two alternate methods of construction the number of gussets, drilled and countersunk holes, machine screws, nuts and bolts required per item as well as the estimated difference in set-up and assembly time was computed. All other costs were considered equal as between the two methods of construction. No allowance was made for the additional material which would be required by reason of the increased length of the items if gusseted construction were used because valid methods of evaluating this are not available. Figures for savings are therefore very conservative.

Cost Analysis Four-Position Receiving Table

Material

Item	Cost
1. Maple Plywood Tops, 7/8" thick, 66" x 20" and 66" x 23"	$ 7.56
2. Cold Rolled Stretcher Leveled Steel Sheet.	
(a) 1/36 of 48" x 96" x #11 Ga	.19
(b) 1 1/4 48" x 120" x #14 Ga	6.95
(c) 1/8 of 48" x 96" x #16 Ga	.59
(d) 1 48" x 96" x #18 Ga	2.96
3. Steel Angles and Bar Stock.	
(a) 32 Feet 1" x 1" x 1/8" Cold Drawn Steel Angle	4.32
(b) 42 Feet 1 1/2" x 1 1/2" x 1/8" Steel Angle	2.08
(c) 7 Feet 2" x 1" x 1/8" Steel Angles	.43
(d) 1 1/2 Feet 1/2" x 1/8" Steel Strap	.02
(e) 2 Feet 3/4" x 1/8" Steel Strap	.03
Total Material Cost	$25.13

Labor

Item	Cost
1. Cutting, drilling, finishing and installing wood tops	$ 7.12
2. Cutting of angles, shearing and braking	11.62
3. Setting up and positioning between welds	4.29
4. Welding.	
(a) 5/16" Fillet Welds. 193" at .104	2.70
(b) Butt and Flush Corner Welds. 90" at .019	1.71
5. Grinding	.76
Total Labor Cost	$28.20

Finishing

Item	Cost
1. Total cost of spray enameling and baking	$ 2.74

Recapitulation

Material, $25.13 plus Labor, $28.20 plus Finishing, $2.74 plus Overhead (at 45%), $25.23 gives Total Cost, Arc Welded $81.30

Comparison of Arc Welded and Gusseted Construction

Item	Cost
1. Additional material required for gusseted construction.	
(a) 1/4 of 36" x 96" x 11 Ga. C. R. Steel Sheet	$ 1.44
(b) Screws, nuts and lockwashers	3.40
Total	$ 4.84

2. Difference in labor costs.

	Welded	Gusseted
(a) Welding	$4.41	....
(b) Cutting and forming gussets	....	$ 5.70
(c) Drilling and countersinking holes	....	9.12
(d) Setting up and assembly	4.29	8.85
(e) Grinding	.76	....
(f) All other labor costs are equal	....	....
Totals	$9.46	$23.67

Net Increase—Gusseted Construction—Labor $14.21

Recapitulation

Increased Material, $4.84 plus Increased Labor, $14.21 plus Overhead (at 45%), $8.57 gives $27.62 as Total Increase—Gusseted $81.30 plus $27.62 gives Total Cost, Gusseted $108.92

Cost Analysis 256 Jack Switching Turret
Material

1. Cold Rolled Stretcher Leveled Steel Sheet.

(a) 1/5 of 40″ x 96″ x #12 Ga.	$ .95
(b) 1 42″ x 144″ x #12 Ga.	7.95
(c) 2/3 of 36″ x 96″ x #16 Ga.	1.82
(d) 1 40″ x 96″ x #18 Ga.	2.50
(e) 1/6 of 36″ x 96″ x #22 Ga.	.24

2. Steel Angles and Bar Stock.

(a) 12 Feet 1½″ x 1½″ x 3/16″ Cold Drawn Steel Angle	3.72
(b) 8 Feet 1½″ x 1½″ x 3/16″ Steel Angle	.64
(c) 2 Feet 1½″ x 1½″ x ⅛″ Steel Angle	.11
(d) 4 Feet 1⅜″ x ⅞″ x ⅛″ Steel Angle	.16
(e) 30 Feet 1½″ x 1½″ Cold Rolled Steel Bar	5.40
(f) 8 Feet ½″ x ⅛″ Steel Strap	.08
Total Material Cost	$23.57

Labor

1. Cutting of angles, shearing and braking	$ 9.08
2. Setting up and positioning between welds	3.79
3. Welding.	
(a) ¼″ Fillet Welds. 31 Feet at .08	2.48
(b) Butt Welds. 5 Feet at .12	.60
4. Grinding	.38
5. Slotting, drilling and tapping jack panel supports	22.23
Total Labor Cost	$38.56

Finishing

1. Total cost of spray enameling and baking .... $ 2.22

Recapitulation

Material, $23 57 plus Labor, $38 56 plus Finishing, $2 22 plus Overhead (at 45%), $28.95 gives Total Cost Arc Welded.................. . ...$93.30

Comparison of Arc Welded and Gusseted Construction

1. Additional material required for gusseted construction
   - (a) $\frac{1}{16}$ of 36" x 96" x 11 Ga C R Steel Sheet $ .96
   - (b) Screws, nuts and lockwashers. 2.10

   Total .. .. . $ 3 06

2 Difference in labor costs

	Welded	Gusseted
(a) Welding .. .	$3 08	. ....
(b) Cutting and forming gussets		$ 4 10
(c) Drilling countersinking, tapping holes ..		5 30
(d) Setting up and assembly	3 79	7 88
(e) Grinding	38	
(f) All other costs are equal		
Totals	$7.25	$17.28

Net Increase—Gusseted Construction—Labor $10.03

Recapitulation

Increased Material, $3.06 plus Increased Labor, $10.03 plus Overhead (at 45%), $4.89 gives $17.98 as Total Increased Cost Gusseted $93.30 plus $17.98 gives Total Cost, Gusseted...$111.28

Cost Analysis Four-Position Sending Storage Table
Material

1. Maple Plywood Tops, $\frac{7}{8}$" thick, 3 pcs. 56" x 28"............... ....$12.70
2. Cold Rolled Stretcher Leveled Steel Sheet.
   - (a) $1\frac{1}{4}$ 36" x 120" x #14 Ga.................................. . . .. 5.40
   - (b) $\frac{1}{2}$ of 36" x 96" x # 16 Ga........ .... 1.36
   - (c) $\frac{1}{3}$ of 48" x 96" x #16 Ga... 1.21
   - (d) $\frac{1}{2}$ of 36" x 120" x #18 Ga... 1.43
   - (e) 1 48" x 96" x #18 Ga... 2.96
   - (f) $\frac{1}{12}$ of 36" x 96" x #22 Ga.... .... .75
3. Steel Angles and Bar Stock.
   - (a) $42\frac{1}{2}$-Feet of 1" x 1" x $\frac{1}{8}$" Cold Drawn Steel Angle.......... 6.37
   - (b) 28-Feet of $1\frac{1}{2}$" x $1\frac{1}{2}$" x $\frac{1}{8}$" Steel Angle.............................. 1.54
   - (c) $7\frac{1}{2}$-Feet of 1" x 1" x $\frac{1}{8}$" Steel Angle.................................. .30
   - (d) 7-Feet of $\frac{1}{2}$" x $\frac{1}{8}$" Steel Strap... .07

   Total Material Cost $34.09

Labor

1. Cutting, drilling, finishing & installing wood tops	$ 8.08
2. Cutting of angles, shearing and braking	9.03
3. Setting up and positioning between welds	2.56
4. Welding.	
(a) 3/16" Fillet Welds. 268 inches at .014	3.75
(b) Butt and flush corner welds. 87 inches at .019	1.65
5. Grinding	.52
Total Labor Cost	$25.59

Finishing

1. Total cost of spray enameling and baking.... $ 2.94

Recapitulation

Material, $34.09 plus Labor, $25.59 plus Finishing, $2.94 plus Overhead (at 45%) gives Total Cost, Arc Welded $90.80

Comparison of Arc Welded and Gusseted Construction

1. Additional material required for gusseted construction.

(a) 1/3 of 36" x 96" x #11 Ga. C. R. Steel Sheet	$ 1.92
(b) Screws, nuts and lockwashers	4.10
Total	$ 6.02

2. Difference in labor costs.

	Welded	Gusseted
(a) Welding	$5.40	....
(b) Cutting and forming gussets	....	$ 7.60
(c) Drilling and countersinking holes	....	12.16
(d) Setting up and assembly	2.56	8.64
(e) Grinding	.52	....
(f) All other labor costs are equal	....	....
Totals	$8.48	$28.40

Net Increase—Gusseted Construction—Labor $19.92

Recapitulation

Increased Material $6.02 plus Increased Labor $19.92 plus Overhead (at 45%) gives $37.51 as Total Increased Cost—Gusseted. $90.80 plus $37.51 gives Total Cost, Gusseted $128.31

Total Cost Saving in Percentage—Conclusion

	Gusseted Cost	Welded Cost	Net Saving
Four-Position Receiving Table	$108.92	$ 81.30	$27.62
256 Jack Turret	111.28	93.30	17.98
Four-Position Sending Storage Table	128.31	90.80	37.51
Reperforator Switching Unit Complete	$348.51	$265.40	$83.11

$$\frac{\text{NET SAVING}}{\text{GUSSETED COST}} \text{ equals } \frac{\$83.11}{\$348.51} \text{ equals } 23.8\%$$

23.8% equals percentage cost saving arc welded!

Estimated Total Annual Gross Savings—(a) Calculation of the estimated total gross savings for a period of years is impossible because variation in business conditions will necessarily affect the policy of the company as to the scope of new installation programs.

However it is possible to calculate these savings accurately for the year 1942 since a definite program for this year is now under way. Savings for future years may fall above or below these figures depending upon business conditions.

Following is a computation of the total gross saving for 1942 based on the installation of partial reperforator switching systems in 18 cities and complete reperforator switching systems at Dallas and St. Louis.

The total number of the items described in this paper which will be required for the 1942 program is as follows:

Four-Position Receiving Tables	155
256 Jack Switching Turrets	52
Four-Position Sending Storage Tables	105

On the basis of the savings indicated in the cost analyses herewith, the total savings for 1942 by the use of arc welding as compared with gusseted construction may be computed as below:

		Saving	Total
Four Position Receiving Tables	155 at	$27.62	$4,281.10
256 Jack Switching Turrets	52 at	17.98	934.96
Four Position Sending Storage Tables	105 at	37.51	3,938.55

Total Saving for 1942....$9,154.61

The above tabulation of savings does not take into consideration the saving in rental for the additional floor area in the operating rooms which would be required if gusseted tables were used instead of the arc welded type. A computation of the savings accruing as a result of the reduction in floor area requirements could not be made unless a complete redesign of the unit were undertaken. This would necessitate a detailed study of the proper relocation of equipment on the various items involved, taking into consideration the limitations imposed by operating practices etc. Such a study is beyond the scope of this paper and it is believed sufficient to merely call attention to the fact that considerable additional savings in this respect are made possible by arc welded construction.

(b) Since industry in general will not produce structures of the type described in this paper, no data on this factor of judgment can be given.

Advantages Contributed by Arc Welding—The advantages to which arc welding has contributed directly as set forth in this paper may be summarized as follows:

1. Improved communication as realized by
   (a) Reduction of message handling time to 25 per cent of the time required for manual handling.
   (b) Gain in accuracy of message handling.
   (c) Increase of circuit capacity.
2. Reduction of physical and mental effort and fatigue of the operating personnel.
3. Increased structural strength and rigidity of equipment.
4. Economy of critical war materials.
5. Economy and facility of production of this equipment.
6. Economy of space requirements, thereby directly reducing office rental costs.
7. Reduction of maintenance costs.

In addition to the use of arc welding in the construction of the equipment described herein, maximum use is made of this modern method of manufacture in the design of many other structures used in the central offices of the telegraph company, and for providing private wire facilities for large customers.

Among the more important of these structures may be listed the following:

1. Carrier telegraphy equipment racks and switchboards.
2. Main office distributing frames.
3. Office furniture and miscellaneous operating room tables.
4. Facsimile telegraphy operating tables and concentrators.
5. Large equipment assemblies and "streamlined" operating tables and turrets for private wire networks for large users such as the U.S. Steel Corp., Federal Reserve Bank System, Sears Roebuck and Co., United Airlines and Government Agencies.

Chapter XIII—Special Check-Writing Machine

By John H. Gruver
Designer, Addressograph-Multigraph Corporation, Euclid, Ohio

John H. Gruver

Subject Matter: The machine, weighing 3,260 pounds though of complex mechanism, runs very quietly and smoothly, in part due to the fitting and alignment of parts to an arc welded steel bed. This bed was to have been made of 4 cast iron members bolted together. Because of difficulty in getting precision alignment with this design, the bed was redesigned and made of welded structural steel. The weight of the bed was thus reduced from 1,200- to 420-pounds and other advantages obtained, including increased life of the machine. The welded beds cost only one-fifth of the cast iron beds (for 6 machines), and saved 8.3% on the cost of the machine.

Machine Description—Simultaneously with the imprinting of checks, this special check-writing machine produces a check copy and three vouchers, or transcripts. In addition, it will imprint envelopes for the checks, addressing and numbering them. The machine produces 4,600 imprinted checks per hour.

The check copy and three vouchers are fed through the machine and turned twice on angular bars. When completed, the vouchers show ten impressions uniformly spaced. These vouchers are then automatically cut into sheets, page numbered, certificate imprinted, reversed, and stacked in numerical order.

Major units of the machine include a pneumatically-operated feeder for the checks and envelopes; four-paper supply rolls individually driven by motors; and five imprinting stations automatically controlled. A dual-plate discharge makes possible continuous operation of the machine without interruption.

The control unit governing the synchronous operation of the imprinting stations, the plate movements, the paper feed, and the page numbering units, is an additional interesting development which has been incorporated in this machine.

The forced feed lubrication system is another interesting feature, with its approximately 200 tiny copper oil lines reaching from a master cylinder to all points of friction and to remote and otherwise inaccessible bearings throughout the machine.

There is also a unique mechanical and electrical safety device which automatically shuts off the entire machine should any operating unit fail to function properly. Simultaneously, a trouble light signals to the operator the source of trouble.

Despite the complexity of its mechanism, the machine runs quietly and with surprising smoothness. This fact is attributed not only to the use of harmonic developed cams and precision bearings, but to the skillful fitting and alignment of parts to a sturdy and secure arc welded structural steel bed, upon which rest 3,260 pounds of the machine's weight.
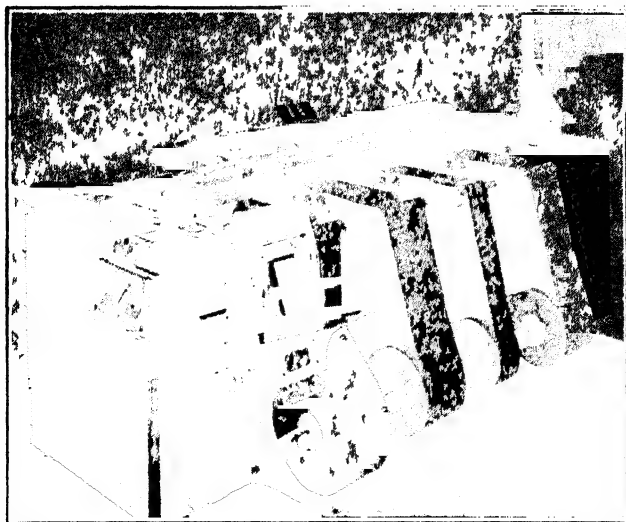
Fig. 1. Spool side of check-writing machine.

Arc Welding in the Evolution of Co-ordinated Design—When the bed of this Special Check Writing Machine was first designed, the stipulations were that the construction should consist of four cast iron members bolted together. This type of construction presented problems as to machining for maximum accuracy to accommodate the precision alignment of the functional units, and a search was therefore made for another method of construction. The remarkable possibilities of arc welding were investigated and its applicability was studied carefully. After a thorough investigation it was decided that the desired results could be obtained by adopting this method. The bed was therefore redesigned and constructed of arc welded structural steel.

Through the use of this advanced method of fabrication it became possible to redesign a bed constructed in one welded unit instead of four cast iron members bolted together, and at the same time reduce the length of the machine from nine and one-half feet to six and one-half feet, and the weight from approximately 1,200-pounds to 420-pounds.

The simplicity of this construction also made it possible to machine the entire length of the bed to a degree of perfection so as to maintain the accurate alignment of the vital functional units. Likewise, it advantageously permitted the drive units, consisting of the motor, speed reducer, and vacuum pump, to be mounted in one compact assembly within the structure of the bed.

Because coordination in the design of the machine evolved through simplified construction which was made possible by the use of arc welding, this check writing machine, despite its size, has a compact business machine appearance. This fact can be readily appreciated by inspecting the photograph, Figs. 1 and 2.

Proportionate Cost Savings—The use of the arc welded bed construction permitted a saving of 8.28 per cent, as compared to the cost of cast iron construction. However, this was not the only cost reduction which was realized, as the use of the arc welded one-piece bed reduced assembly cost considerably.
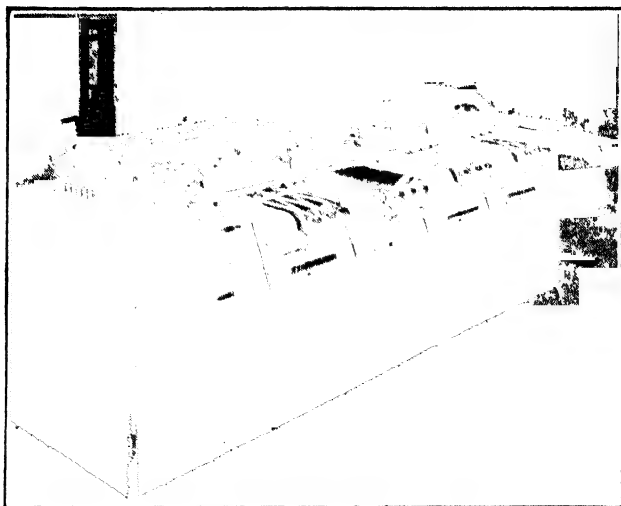
Fig. 2. Arc welding permitted simplified construction.

Gross Savings Accruing—The adoption of arc welded construction not only resulted in savings in material and machining labor, but also eliminated the necessity for pattern equipment and temporary tools. The table which follows shows the savings effected by the use of arc welding in the manufacture of our special check-writing machines.

Cast Iron Construction Cost	1 Machine	6 Machines
Pattern Equipment	$ 563 00	$ 563.00
Temporary Tools	219.00	219.00
Assembly Material	37.50	225.00
Machine & Material	795.00	4,770.00
	$1,614.50	$5,777.00
Arc Welded Steel Cost		
Material	$ 21.00	$ 126.00
Machining	174.00	1,044.00
	$ 195.00	$1,170.00

As shown in the foregoing figures, total savings resulting from the use of arc welded steel construction for the beds of these machines amounted to $1,419.50 for one machine and $4,607 for the six machines

Increased Service Life, Accuracy and Efficiency—The service life of this entire complex machine, (the Division of Disbursements, U. S. Treasury, has six of these machines in constant operation), was increased because the intricate operating mechanisms were assembled securely to a rigid one-piece bed. This bed, which has a length of six and one-half feet, has had the entire top surface machined by a .050-inch planer cut, thus proving the accuracy of arc welded construction.

As a consequence, these machines are meeting, efficiently and effectively, today's heavy production schedules because the welded construction endures continuous peak production.

Conclusion—Although our experiment with arc welding had proven most profitable, welding engineers were called in to inspect the welded bed. They were able to offer suggestions which contributed to the making of further improvements on the five additional special check-writing machines which were subsequently constructed and delivered to the Division of Disbursements, U. S. Treasury, Washington, D. C.

Chapter XIV—Downdraft Ventilation for Welding Shop

By Hugh T. Monson

Plant Engineer, The Euclid Road Machinery Co., Euclid, Ohio

Hugh T. Monson

Subject Matter: Unsuccessful attempts were made to exhaust the smoke-laden air from a large welding shop and welding booths, each to accommodate four welders and taking assemblies up to 16 feet wide, were then designed for welded construction, with downdraft ventilation provided by fans which exhaust the air through 42-inch stacks. The cost of the booths is estimated as $2,258 and of the whole installation $11,137. It is believed that 5–10% greater production will result from the improved working conditions.

Present-day production in our era of world crisis leans heavily upon electric welding for producing equipment varying from huge battleships to small motors.

In this wide range of products is a group of manufacturers fabricating items whose size is of neither extreme mentioned above. They make army tanks, trucks, busses, etc., that generally require indoor fabrication of large welded assemblies.

The writer is engaged in a company manufacturing earth-moving equipment. This company, like all the others manufacturing articles of similar size, has struggled with the problem of properly ventilating the welding shop.

The Problem—Welding without proper ventilation is annoying, but is not a serious health hazard. Welding of galvanized sheet metal may cause a temporary illness, or fever, commonly known as "zinc shakes" or "galvo" caused by the breathing of zinc oxide in the form of a typical welding fume.

Metal-fume fever, if acquired, is a condition which usually passes off within a few hours. It is seldom encountered, for its acquisition through breathing iron oxide, the most common of the metallic oxides, is quite problematical.*

However, there is a more serious problem than health to the average industry. Improper ventilation results in less production, for the following two reasons:

(1) Too much smoke or welding fumes cause more time to be taken off for fresh-air walks and for drinks of water.

(2) Too much heat accumulates around the welder in warm weather.

The problem therefore is to obtain proper ventilation around these large assemblies in order that we may better working conditions and thereby increase production.

*"Control of Welding Hazards in Defense Industries" Special Bulletin No. 5, United States Department of Labor.
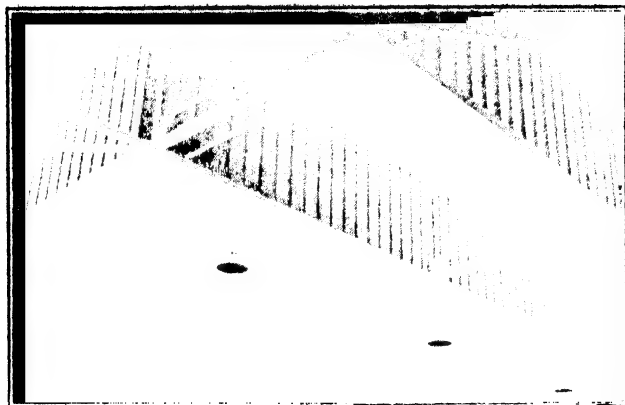
Fig. 1. The two hoods.

Development of the Problem—In the plant with which the writer is associated, increased use of welding in manufacturing, added to a healthy business growth, presented the welding ventilation problem.

The solution to this problem was placed in the hands of the author in line with his regular duties.

As an introduction to the investigation of the welding smoke problem, manufacturers of fans, welding wire, and welding machines were consulted. Very few suggestions were received, but the consensus of opinion was to exhaust the welding area in a general way, for the product was too large to set up in conventional booths—and to make it more complicated—hoods could not be used because the various parts making up the assemblies were so heavy that overhead traveling cranes were required throughout the welding plant to handle the production material.

The welding bay is 50-feet wide by 116-feet 6-inches long, with a ceiling height of 27-feet. It is adjacent to the structural fabricating department and had no separating wall or partitions between. This open condition allowed the smoke nuisance to be general throughout the plant, for the blowers on the unit heaters would distribute the smoke quite generally. Complaints were numerous.

The first step in the solution was to put a steel curtain wall between the structural and welding bays from the ceiling to within ten feet of the floor. A fan was placed in the welding shop on each end of the building monitor to create a general flow of air from the structural to the welding bays, thus preventing smoke from leaving the welding department. The two fans thus purchased moved 20,000 c.f.m. of free air, giving a general flow of air under the curtain wall of

$$\frac{20{,}000 \times 2}{10 \times 116.5} \text{ or approximately 24-lineal feet per minute.}$$

Results were immediate in every department except the welding shop itself. There no longer was any smoke in other parts of the plant, but the welders still had heavy smoke-laden air to breathe. It was apparent that more air had to be removed, but was it practical to exhaust so large an area as this—178,000-cu. ft.?

It was decided to let the problem ride along for a while—in the meantime further consulting would be done.

Fig. 2. Welding in the paint booth. Note flow of smoke.

The next practical suggestion came from a representative of the Cleveland Safety Council who suggested that a fan-vented hood be built over the large assemblies in the building trusses above the crane runway. This is high for a hood, but it seemed practical for most of the welding was concentrated in these large assemblies.

A large hood 18-feet wide by 40-feet long by 6-feet deep was built over the one area for large assemblies. Considerable ventilation was needed, so a large fan was placed in a penthouse above the roof and located centrally in the hood. This fan moves 29,000 c.f.m. of free air.

The new installation improved the condition further. Smoke would rise into the hood and immediately be exhausted. The improvement warranted doing the same thing over the other welding assembly station, so another hood was built. These two hoods are shown in Fig. 1. One hood is shown almost completely, and a portion of the inside of the second is shown in the upper right-hand corner of the photograph. The building monitor runs between the two hoods.

Throughout the development of ideas on this problem the shop welders have offered suggestions. Through their union representatives, they requested that a flexible tube, local exhaust system be installed for miscellaneous welding of small parts. This was done but did not prove very satisfactory, for the men did not want to continually move the flexible tubes. It is now totally discarded.

Direct cost of this entire development to date is as follows:

Item	Cost
Steel Curtain Wall, Installed	$ 926.00
Fans in Monitor, Installed	491.00
Hoods over Assemblies, Installed	902.00
Fans in Hoods	508.00
Flexible Tube, Local Exhaust System, Installed	932.00
Penthouses for Hood Fans	230.00
Electrical Wiring—Estimated	400.00
Unit Heaters, Installed	375.00
Total	$4764.00

This brings the physical progress up to date in the welding shop. The problem is partly solved but definitely not satisfactorily solved.

Progress, in America at least, always stimulates the desire for further improvement, and the progress made on the problem herein discussed is no exception.

A New Idea—While the company was engaged in the welding ventilation problem, another problem was being solved. This problem was the removal of fumes and spray particles from spray painting. It was solved with a patented DeVilbiss downdraft water-wash exhaust booth.

The author conceived the idea that perhaps this new system would work with welding smoke. However, there are two fundamental differences between removal of spray paint and welding smoke:

(1) Spray paint particles are heavier than air and tend to settle, while smoke particles are nearly the same weight as air and tend to rise because of the heat generated by the arc in welding.

(2) Spray particles have considerably more inertia, which affects their movement.

Welding in the existing paint shop would certainly be worth a trial to determine the results.

The Experiment—The welding fixtures for a truck body were set up in the paint shop on Thursday, May 21, 1942. A truck body was selected for the test for it seemed the most difficult of the assemblies from an air-flow point of view, due to its eight-foot width through which no air could flow.

The results were very satisfactory and are indicated in the following photographs.

The sides of the truck body are first welded. Fig. 2 and Fig. 3 show this welding in the paint booth and the flow of smoke. Smoke flow is away from the operator and does not get up to his helmet. Fig. 4 shows the same set-up in the present shop under the hood mentioned previously. A corner of this hood is shown in the upper left-hand corner. The smoke does not show in this photograph, but it was rising straight up.

The second welding position on the body is shown in Fig. 5 and Fig. 6 in the booth, and Fig. 7 in the usual location in the shop. Fig. 5 shows the

Fig. 3. Another view of welding in the paint booth illustrating smoke flow.

smoke as it leaves the arc and flows under the helmet. Fig. 6 shows better the continuation of the smoke flow past the man's legs. Fig. 7 shows the existing conditions—how the smokes goes upward past the man's helmet. Under these conditions a welder breathes the welding fumes—he cannot do otherwise.

The third set-up is welding inside the body. Fig 8 and Fig. 9 show these positions in the booth and in the shop respectively. It is nearly impossible to see any smoke in Fig. 8, since it did not record very well on the film. However, the smoke went up eighteen inches or so above the body and then came downward along the outside of the body. The difference in atmosphere above the truck body in each of the pictures can readily be noted, for there is a considerable amount of smoke above the welders in Fig. 9.

Since these assemblies stand rather high in this booth (a 12-foot booth), it was decided to make the welding booth two feet higher, or 14-feet overall.
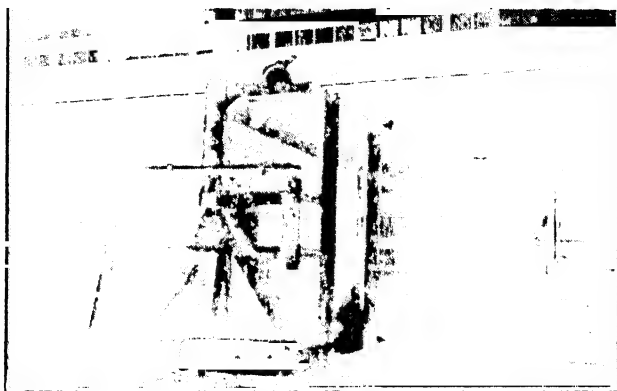
Fig. 4. Welding under hood.

Design and Description of the New Booth—The design of the new booth was made by the author upon principles given him by The DeVilbiss Co., manufacturers of downdraft booths for spray painting.

This special downdraft arrangement consists of one side-enclosed chamber, or booth, with a pair of three-section folding doors on one end. It is open at the top to permit the entrance of free air.

The booth has a top opening of 12 x 24-feet or 288-square feet. The air moved through this booth is 45,060-cubic feet per minute, leaving a lineal or facial velocity through the top opening of 156-feet per minute. This is somewhat in excess of the velocity used in paint spray booths, which runs about 125 to 135-feet per minute. The excess velocity was thought desirable because of the heat generated by the arc. It should be noted that working in moving air of this velocity does not seem to cause any objectionable drafts.

The top of the side walls slope inward at an angle of 45 degrees, and along these slanting panels there are openings to accommodate 12 light reflectors of a long range design which will accommodate 300- to 500-watt light bulbs.

An area 16-feet wide by 24-feet long is provided for the road machinery assemblies to be welded in the booth. The 14-foot sides of this enclosed area are supported by six 4-inch pipes imbedded two feet in concrete. There are no cross braces on the top opening so that material may be handled into and out of the booth freely with an overhead traveling crane.

The air entering the booth at the top flows downward to the bottom of

each of the side walls where it enters a two foot wide opening running the full length of the booth. Passing through this opening it enters a chamber nine feet high by two feet wide. The air flows along this chamber to the rear of the booth where it enters a 42-inch vertical stack through which it is exhausted to the outside atmosphere. There is a vertical stack for each side of the booth, each containing an exhaust fan which moves 22,530-cubic feet of air per minute at ¼-inch static pressure. Each of these fans is driven through a Vee-belt drive by a 3-horsepower, 1725 revolutions per minute motor specified for 220 volts, 60-cycle, 3-phase current.

Two design characteristics should be here noted:

(1) That the side air chambers (9-feet x 2-feet) are rectangular in vertical cross section from front to rear of the booth. This nine foot dimension is maintained for the full length in order that the point of minimum quantity of air flow (the front of the booth) has the minimum amount of air restriction.

(2) That ¼-inch static pressure is used for calculating fan specifications in dry systems with normal flow restrictions.

It should be noted also that the exhaust stacks, which extend about 6 feet above the roof, are located in a lean-to about ten feet high at the rear of the shop. This lean-to is an existing building.

Provision is made to anchor the stacks with guy wires and to drain rain water from the base of the stacks. Automatic dampers are located in the stacks to prevent cold air from being drawn into the building by exhaust fans in other booths if the booth is not in operation. A roof flange is provided, and also a removable panel for access to the exhaust fan.

The sides and rear of the booth are constructed of 2-inch x 2-inch x ¼-inch angles welded into three separate frames for each side and the rear. To these frames are welded the same size angles for vertical reinforcement approximately every three feet along the length of the panel. Each frame is covered by 18-gauge black steel sheet tack welded to the frame. Air chambers, doors, etc., are of similar construction—2-inch x 2-inch x ¼-inch angle framework covered by 18-gauge sheet. Sides are welded to pipe columns and remaining assembly are welded together.

The booth is painted dull black inside and out to minimize welding arc reflections.

Fig. 5. Second welding position in booth.
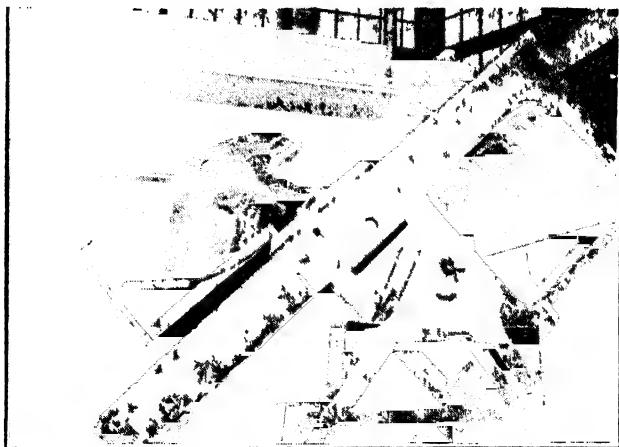
Fig. 6. Another view of the second welding position in booth.

Shop Layout—Four booths are provided as shown—two 16-feet wide and two 12-feet wide.

The 12-foot booths are of the same construction as the 16-foot booths. They are provided with two JJ-607 DeVilbiss 34-inch diameter propeller-type fans each moving 14,750 c.f.m. of air at ¼-inch static pressure. Each fan is driven by a 2-horsepower 1725 revolutions per minute motor. The top opening for these booths is 9-feet wide and the bottom openings at base of each side panel are 18-inches high. The width of side air chambers is also 18-inches.

The steel curtain, shown on drawing, is raised to within seven feet of the shop ceiling which cuts the velocity of air flow from the main plant, from which half of the 159,120 c.f.m. required for all booths will be drawn. This leaves a lineal air velocity of approximately 34-feet per minute.

The flow of material through the welding shop is indicated by arrows. It comes in from the fabricating or structural department as shown and leaves for painting where shown.

All welding will be confined to the booths with the exception of tack welding in set-up areas indicated. Smoke from set-up welding will be exhausted from these same booths, for all present fans will be removed leaving all air flow through the booths.

Four welding machines are provided in each booth. One man of the four operating in each booth will be a booth foreman, responsible for the output of his booth because the enclosure prevents the welding supervisor from watching operations.

Large assemblies will be welded in the two large booths; small parts and smaller assemblies will be welded in the smaller booths.

Welds will be cleaned in the building where indicated.

Three unit heaters will be provided as shown. One heater will operate on and off automatically with each of the two large welding booths. The third heater will operate automatically with either or both of the small booths. All intake air for these units is to be taken from outdoors.

Cost Savings through Installation of New Booths—Since the welding smoke is still such a nuisance in the welding shop, it is known that its elimina-

tion will improve working conditions for the two reasons previously mentioned: the smoke nuisance in winter will be practically eliminated, and the heat nuisance in summer will be greatly reduced.

Because this idea of downdraft ventilation was conceived too recently to get any further than the design and experimental stage at the time of writing this paper, the proportional cost saving over the previous ventilation method —in terms of production—can only be estimated.

For calculation purposes this will be estimated low. The author, the methods department, and the factory manager believe a ten percent increase in production can be attained by improving working conditions as proposed, but for purposes of calculation a five percent increase will be used. It is certain that three minutes out of every hour will be saved in this shop.

This saving applies to the welders in each of the four booths and to everyone working in the welding department. In calculating the annual saving derived, only the welder's time will be figured. The output of the weld chippers, or cleaners, will not be taken into account, in order that the estimates made will be even more conservative.

Fig. 7. Smoke travels upward past the welders' helmets.

Estimated Total Annual Gross Cost Savings—The total annual savings derived from the installations of the arc welded booths in the company with which the author is connected will be again translated into terms of production in view of the fact that this company will not manufacture these booths for sale, but will use them as a means to cut costs in its own product.

The gross annual saving to be derived will be as follows:

The welding shop has been operating ten working hours a day on a five day per week basis with two shifts or 100 hours per machine per week.

For twenty machines there will be 20 x 100 x 52 or 104,000 hours per year.

At the company rate of $2.50 operating cost per hour, the total yearly cost of operating this number of hours is

$$104{,}000 \times 2.50 = \$260{,}000 \text{ per year}$$

Increasing production five percent means that the company would produce

$$\frac{105}{100} \times 260{,}000 \text{ or } \$273{,}000 \text{ worth of work for } \$260{,}000$$

The company, therefore, would save $13,000 per year.
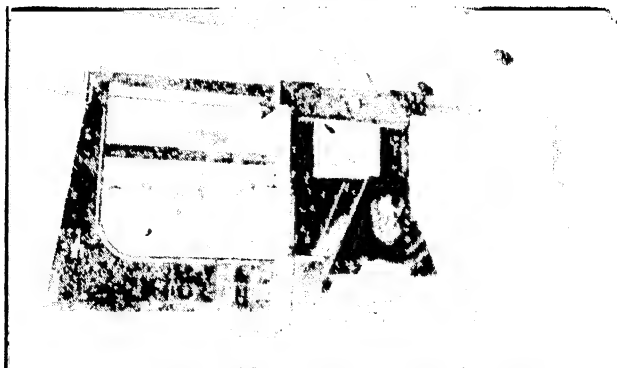
Fig. 8. Third setup of welding inside the booth.

Since there are operating costs in connection with the installation of these booths, these should be deducted.

The operating costs include costs of electric current and coal used to replace heat removed from the building.

The two large booths use six horsepower each, and the small ones four horsepower each. The heating units each require a five horsepower motor.

$$(2 \times 6) + (2 \times 4) + (3 \times 5) = 35 \text{ horsepower.}$$

Since 14 horsepower will be eliminated by removing the present fans, the net horsepower addition will be

$$35 - 14 \text{ or } 21 \text{ horsepower}$$

Assuming that these motors are 85 per cent efficient, the input to them is —since there are 746 watts in one horsepower—

$$\frac{21 \times 746}{.85} = 18{,}430 \text{ watts or } 18.43 \text{ kw.}$$

Operating these motors 20 hours per day at the company cost of .67 cents per kwh.

$$20 \times 18.43 \times .67 = 246 \text{ cents or } \$2.46 \text{ per day}$$

$$2.46 \times 5 \times 52 = \$639.60 \text{ per yr., added cost of electric current for motors}$$

Cost of operating additional booth lights, assuming they will require light 15 hours a day for all 48 of the 500 watt lamps:

$$\frac{48 \times 500 \times 15 \times .67}{1000} = 241 \text{ cents or } \$2.41 \text{ per day}$$

$$2.41 \times 5 \times 52 = \$626.60 \text{ per yr. added cost of electric current for lamps}$$

$$\$639.60 + \$626.60 = \$1266.20 \text{ yearly cost of electric current}$$

The first heat calculation to make is the determination of heat capacity in B.T.U. per hour required to replace the heat loss of the air exhausted. This is necessary to determine the size of the unit heaters required.*

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*Heat calculations were made with the assistance of Mr. Valentine of the Consulting Engineering firm of Mayer & Valentine of Cleveland, Ohio.

There are 159,120 c.f.m. of air exhausted from the four booths. The temperature to be maintained in the welding department is 60 degrees F. when the outside temperature is 10 degrees above zero. The factor 55.5 is used to convert cubic feet air per hour ihto B.T.U. per hour for a given temperature rise. C.F.M. must be converted to cubic feet per hour.

$$\frac{159{,}120 \times 60\ (60-10)}{55.5} = 8{,}600{,}000 \text{ B.T.U. per hour}$$

After a check was made with The DeVilbiss Co. on their experience with heat losses through spray booths, it was decided that half of the heat exhausted would be replaced. This judgment was based on the following reasoning.

Fig. 8. Third setup of welding in the shop.

(1) The area of the main plant from which the remaining 50 per cent of the heat is to be drawn is quite large. It comprises some 777,500 cubic feet.

(2) The construction of this plant is sheet metal and glass through which a considerable amount of heat is lost through openings. This heat will now be taken out through the exhaust system.

(3) Temperatures through the main plant will be maintained more uniformly at the various levels above the floor, because of the amount of air circulation that will be caused by the fans. At present, temperatures in excess of 100 degrees F. exist under the roof. The air circulation will maintain a temperature under the roof that is more nearly the 65 degrees F. working level temperature maintained in this part of the plant. This gives a reservoir from which heat may be drawn, much of which is now escaping through openings in the steel building at temperatures of 100 degrees F. This is perhaps the most important consideration in arriving at this 50 percent figure, for the heat that will normally go to building this temperature up and maintaining it can now be exhausted by the fans without notice.

From this consideration it therefore may be said that 4,300,000 B.T.U. per hour will be provided, and since 500,000 B.T.U. per hour already has been provided for heating air that we now exhaust, this figure should be reduced to 3,800,000 B.T.U. per hour.

Dividing this by the three unit heaters desired, there will be 1,267,000 B.T.U. required of these heaters. Heaters having 1,250,000 B.T.U. per hour were selected.

In order to compute the heat loss per hour for the season and the cost of coal therefrom, it was found that such calculations are based on an average

outdoor temperature of 35 degrees F. for a seven and one-half month heating season in the location in which the company is situated.

$$\frac{159{,}120 \times 60\ (60-35)}{55.5} = 4{,}300{,}500 \text{ B.T.U. per hr.}$$

Since half of this is to be supplied, and of that half there already is provided 500,000 B.T.U. per hour, there are

$$\frac{(4{,}300{,}500)}{2} - 500{,}000 = 1{,}650{,}250 \text{ B.T.U. per hr. to be supplied}$$

This figure is converted into square feet of equivalent direct radiation per hour by dividing by 240,

$$\frac{1{,}650{,}250}{240} = 6{,}876 \text{ sq. ft. of E.D.R. per hr.}$$

Using ¼ lb. steam per sq. ft. E.D.R.

$$\frac{6{,}876}{4} = 1717.9 \text{ lb. steam per hour}$$

Assuming the boilers evaporate 7 lb. of steam per pound of coal burned,

$$\frac{1717.9}{7} = 245 \text{ lb. coal per hour}$$

With a coal cost of $3.89 per ton, and a 20-hour day operation,

$$\frac{245 \times 20 \times 3.89}{2000} = \$9.52 \text{ per day cost of coal}$$

For five day week operation for 7½ month heating season,

$$9.52 \times 5 \times 4.33 \times 7.5 = \$1548.00 \text{ per yr. cost of coal}$$

$$\$13{,}000.00 - (1271.00 + 1548.00) = \$10{,}181 \text{ annual saving with this installation}$$

Cost of the Booths—It was decided to fabricate the welding booth in the company's own plant.

The estimated cost to fabricate and erect this structure is as follows:

8400 lb. steel at $.03 per lb.	$252.00
125 hrs. labor at $2.50 per hr.	312.50
Total cost for 16 ft. booth	$564.50

This figures a cost of

$$\frac{564.5}{8400} \text{ or } 6.72 \text{ cents per lb. for the completed product.}$$

This check seems to be in line with our costs for such a job.
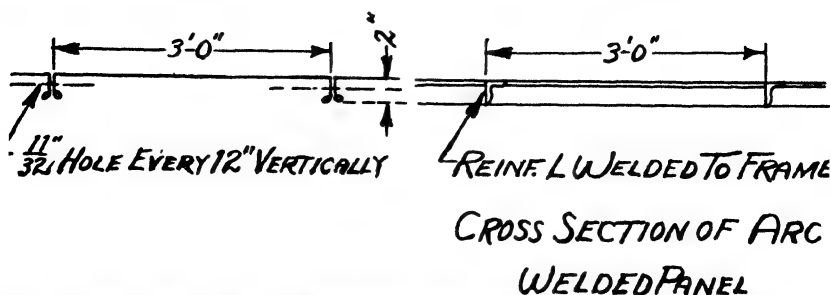
Fig. 10, (left). Cross section of conventional panel. Fig. 11, (right). Cross section of arc welded panel.

An attempt was made to get a comparative cost on a sheet metal booth of the design DeVilbiss uses, but no one was able to submit this figure in sufficient time. The writer's company is not equipped to do sheet metal fabrication.

The sheet metal booth is made up in three foot panels around the sides of the booth as in the design sketched in Fig. 10. Fig. 11 shows the arc welded design.

The sheet metal design requires forming each edge round, bending the sheet at 90 degrees, and punching holes every 12-inches in edges where indicated.

There is a considerable amount of assembly work after the panels are fabricated.

It is believed that this booth would cost 20 per cent more erected than the arc welded booth proposed.

There is little difference in the costs of the 16-foot and 12-foot arc welded booths, so the four will be considered to cost the same price each.

564.50 × 4 = $2,258.00 Total Cost of Booths

Cost of Installation—The cost of this installation is as follows:

Motors and Fans, DeVilbiss Co.	$ 1,712.00
Heating Equipment, estimate by Mayer & Valentine	4,000.00
Light Reflectors, Elliott Electric Co.	167.00
Electrical Installation, estimate by Parker Electric Co., includes labor, switches, controls, conduit, wire, etc.	3,000.00
Welding Booths, Installed	2,258.00
	$11,137.00

Note the comparison of this installation for $11,137.00 against $4,764.00 spent for previous installation which did not reduce welding costs by increasing production.

On this basis the installation would pay for itself in approximately thirteen months, which makes it an excellent investment.

It should be noted that the existing boilers have sufficient capacity to handle this extra heating load, but will have to be forced in extreme weather. Boiler capacity is an important consideration in the analysis of this problem.

Application to Industry in General—The downdraft ventilation idea for welding booths is a new application of an established ventilating idea. The new application has been successfully tested, as previously described and shown. This idea is believed to offer considerable merit for any plant engaged in manufacturing large welded assemblies. If applied, the arc welded booth as herein described can readily be made by the company desiring the booth.

Cost advantages should prove favorable in most all cases.

There is still another suggestion not previously mentioned. In plants welding small bench assemblies, an open steel grating could be used for a table top with downdraft ventilation through the table grating in a similar application.

Social Advantages and Conclusion—This paper so far has treated downdraft ventilation in terms of dollars-and-cents results without much mention of the social advantages to be gained by its adoption.

It means a great deal to a welder's peace of mind to have the room in which he works clear of smoke as soon as he stops welding, and to have the smoke pulled away from his helmet while he is welding. Although the health hazard is not serious, it exists and undoubtedly worries the average workman who is forced to inhale smoke all day.

The welders used in the experiment, and their foreman, showed considerable enthusiasm. They commented that this was something that should have been done long ago, and that at other plants in which they had worked the same problem had been worked on without satisfactory results.

The evening on which the experiment was conducted was somewhat warm, so quite a bit of emphasis was put on the cooling effects of this ventilation. The movement of air not only carries away the heat, but also evaporates perspiration from the body and cools the body accordingly. Welding clothes, of course, are quite warm in the summer time.

The most remembered remark made by any of the welders used in the experiment was,

"We certainly could do a lot more work under conditions like these."

Chapter XV—Thoughtful Welding of Machine Parts

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Subject Matter: Miter gates and gate machinery of unprecedented size are used on the lock lifts to raise ships from the Columbia River to the reservoir behind Bonneville Dam. The machinery includes 4 sector arms subject to large varying stresses, both bending and axial. These were to have been steel castings, each weighing 1,350 pounds but actually were made of a part-cast and part-welded design. In the winter of 1941-42 one failed due to ice in the locks. It was quickly repaired by welding at large saving. The others were then removed, straightened, and reinforced by welding. In 1942 an all welded sector arm was designed, and though of higher "cost in place," it is stronger, more durable, and much more easily and quickly obtained.

A big difference exists between machinery designed for welding and just welded machinery. Where thought is given to modern proportioning of parts, working stress in the welds, time element, fabrication costs, number of individual pieces and final appearance, the resulting machine will be found to be more serviceable, more durable and will frequently cost less initially than a machine that was "just welded". The science of designing welded machinery has progressed in the last five years to a point where predictions of adequate performance can be made if the basic principles of mechanics and metallurgy have been followed in the design.

A case in point is the heavy machinery used to open and close the miter gates on navigation locks. At Bonneville, Oregon, one of the highest lock lifts in the world literally raises ocean going boats from the lower Columbia River to the deep reservoir behind Bonneville Dam. The height of lift and the deep draft of ships necessitated the use of miter gates and gate operating machinery of unprecedented size. The gate machinery is located in the concrete lock wall near the top of the gate and consists of a motor driving through a flexible coupling, gear reducers, gear train, sector wheel, sector arm and an operating strut connected to the gate.

The sector arm, designed by the U.S. Army Engineers in 1935, was a carbon steel casting weighing approximately 1350 pounds. When assembled, it is bolted to the sector with 1¾-inch diameter fitted bolts. The other end of the sector arm is pinned to one end of the operating strut.

Stress in the sector arm is combined bending and axial stress and is figured on the basis of 250 per cent of the normal torque of a 30 horsepower motor running at 792 revolutions per minute. Actual measurements of force to open the large gates in moderate weather and without wind indicate that less than a six horsepower motor is required for this duty. However, the gates must be operated against abnormal loads such as wind, ice and opposing currents in the water. For this reason a large prime mover is chosen and the rest of the machinery designed to resist stresses imposed by this motor operating at a maximum torque of 250 per cent of normal.
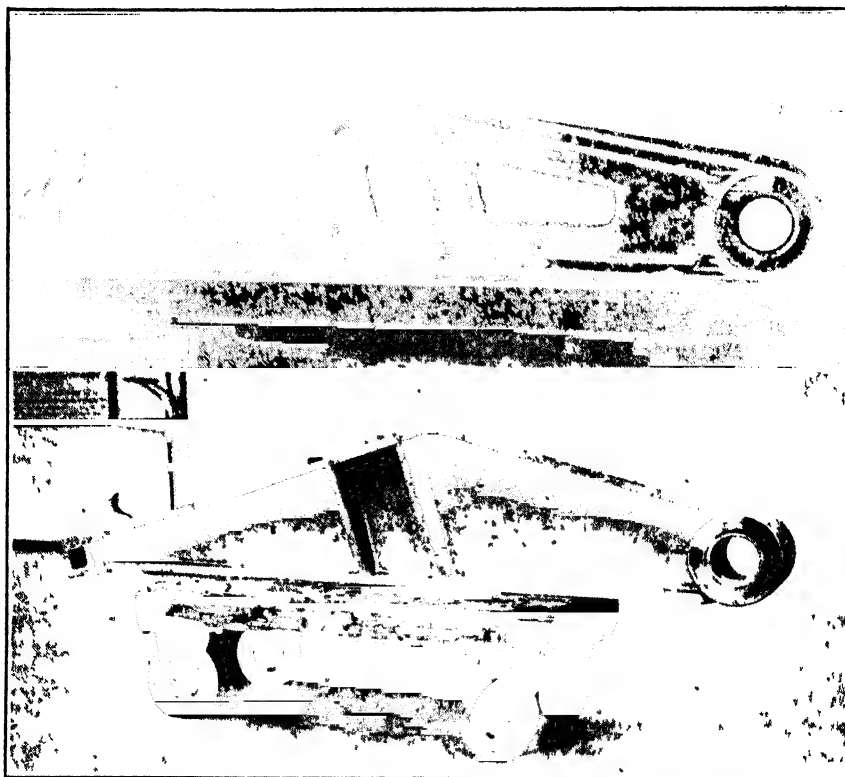
Fig. 1, (above). Old sector arm repaired with welded reinforcing plates. Fig. 2, (below). New arc welded sector arm.

There are only four sector arms required for the navigation lock machinery and the sub-contractor for the machinery elected to fabricate the sector arm of welded steel plate. This design employed a cast steel hub at the pin end and a cast steel bracket on the opposite end of the arm. Fillet welds were used throughout and no vee cuts were made in the parent metal. The lower flange was made of 1¼-inch plate 9-inches wide and 7-feet, 6½-inches long. The web, fillet welded to the flanges and stiffeners, was made of 1½-inch plate and had large lightening holes cut out of it centering on the neutral axis. It is to be noted that the lightening holes were considerably larger than allowed in the cast steel design. This web was carried through the top flange on the pin half of the arm, obviously to provide a more secure grip and longer lengths of fillet welding the cast steel hub. A top flange was made up of four distinct pieces of plate, each fillet welded to the other or to the web and without benefit of beveling or veeing the joints. Welded design of this type was considered acceptable in 1936.

The winter of 1941-42 was an extremely cold one in the Pacific Northwest and ice formed on the Columbia River. An attempt was made to keep the navigation lock gates in operating condition by small, periodic movements during the cold snap. The idea was successful until one of the lock tenders coming on shift swung the gates too far, crushing and packing the ice between the gate and the lock wall. The strain was more than the sector arm

could stand and it failed through the fillet weld and the corner of the middle lightening hole.

Navigation on the river was stopped by ice and there remained about one week in which to repair the broken arm or to fabricate a new one. Steel shortage at this time made it impossible to make a new sector arm in this limited period so the broken arm was reinforced by carefully burning and chipping out a vee on the crack and electric arc welding the severed parts together. Only a small amount of welding rod was deposited in the vee at each pass of the "stinger" and each bead was carefully peened to relieve locked in stresses and to improve the grain structure of the weld metal. In addition to joining the parent metal by arc welding, the three outsize lightening holes were fitted with beveled 1¼-inch plate (the only thickness of steel plate on hand) and welded all around. Drainage was provided by a one inch diameter hole drilled in these fitted plates. The entire repairs and reinforcement of the arm was carried out by arc welding, (See Fig. 1), and the success of this emergency application of the process is indicated by the fact that the reinforced arm has been on duty for five months without apparent distress in any of the parts.

Inspection of the remaining three sector arms showed them to be bent and strained in the same place as the arm that failed. It was decided to

Fig. 3. New arc welded sector arm in position.

make an all arc welded spare sector arm, (See Figs. 2 and 3), to be substituted for the distressed arms, one at a time, and to permit repair and rehabilitation. Straightening the old arms and fitting plates in the outsize lightening holes cost $147.21 per arm divided as follows:

Shop labor (welder and helper)	$60.00
Reinforcing material	13.49
Labor for straightening and machinery	48.00
Shop and supervision expense	25.72
	$147.21

A 1942 machine part, an improved arm, was designed in four hours, material was delivered to the shop in two days and the complete fabrication and finishing took 216 man-hours making a total of approximately 8 days to make a part that would have required at least a month due to priorities, etc., if made of carbon steel casting. The cost was $458.60 divided as follows:

Labor	$217.30
Material	188.14
Shop and supervision	53.16
Total	$458.60

It must be remembered that this arm is subject to the same loads as the original cast steel or the 1936 welded design. It differs from the earlier welded part in three vital respects. First, plate steel is used to make a laminated hub at the pin end instead of using a casting. The opposite end of the sector arm is also built up of arc welded steel plates instead of a casting. This alone saved several days since the pressure of war production made it virtually uncertain when a special casting could be made at local foundries and delivered to the shop. Secondly, the top flange is made of one shaped plate, arc welded to the web. Where extra thickness and a keyway were required, ¾-inch doubler plates were welded on top of the top flange. The third important change was the use of a solid web with relatively small drain holes drilled in it.

Further mention should be made that the new design utilizes one thickness of plate for the web and flanges which is lighter construction than the previous design and permits greater ease in welding and a reduction in shrinkage stresses. The amount of welding on the flanges was reduced by making the top flange continuous through the critical section. The hub was built up of ring plates with the continuous web plate forming the central part of the hub. These ring plates were beveled and a vee weld of sufficient strength used to resist the moment produced by the maximum loading on the pin connecting the arm to the strut.

In order to compute the maximum combined stress, it is necessary to find the strut loading produced by the maximum motor torque for various positions of the sector arm so that the resultant strut loading can be resolved into components perpendicular (P^1) and parallel (P) to the neutral axis of the arm. If there is any doubt about the locations of the critical section, and this is apt to occur since it is difficult to visualize the effect of a combined stress, the stress should be found at several sections along the arm in order to find the maximum. In this particular case the position of the critical section was known because of the failure.

The following table gives data needed for the stress computation and is based upon 250 per cent of the normal torque of a 30 horsepower motor at 792 revolutions per minute and an overall efficiency of machinery of 70 per cent. Position O indicates the position of the sector arm when the gate is in the open, or recessed position, and position 10, gate in closed, or mitered position. The angle, O, is the angle formed by the centerline of the strut and the neutral axis of the outer end of the sector arm,

Position	Max. Strut Load—Lb.	θ Deg.	Load $\perp$ To Sect. Arm	Load $\parallel$ To Sect. Arm
0	245,000	25	103,500	222,000
1	172,000	33	93,700	144,000
2	133,000	43½	91,700	96,500
3	110,000	54	89,000	64,700
4	94,500	66	86,400	38,400
5	86,300	78½	84,700	17,200
6	82,600	93	82,500	4,130
7	85,500	108	81,250	26,400
8	95,200	125	77,800	54,600
9	123,000	142	75,700	96,800
10	214,000	162	66,200	210,000

The combined stress at the critical section is the sum of the compressive, or tensile stress, and the maximum flexual stress, $S = Sc + S_f$

$$Sc = \frac{P}{a} \text{ and } S_f = \frac{Mc}{I} = \frac{P^1 \times c}{I}$$

The cross sectional area of the critical section is 49.35-square inches. The neutral axis is found to be 11.2-inches from the narrow flange, the total depth being 21-inches, the moment of inertia 5,546-inches^4, and the moment arm 36-inches.

$$\frac{P}{a} = \frac{P}{49.35}$$

$$\frac{P^1 \times c}{I} = \frac{P^1}{13.75}$$

The following table gives values of stress for various position of the arm.

Position	P	P^1	$P + P^1$
0	4,500	7,550	12,050
1	2,920	6,800	9,720
2	1,950	6,650	8,600
3	1,310	6,450	7,760
4	770	6,280	7,050
5	348	6,150	6,435
6	84	6,000	6,084
7	535	5,900	6,435
8	1,100	5,670	6,770
9	1,960	5,500	7,460
10	4,250	4,800	9,050

For a comparison, the following table gives pertinent information concerning the strengths of the all welded arm and the welded and cast arm at the critical section.

Item	All Welded Arm	Welded and Cast Arm
Depth of Section	21 in.	18 in.
Area of Section	49.35 sq. in.	34.5 sq. in.
Moment of Inertia	5,546 in.^{4}	1,986 in.^{4}
Max. Section Mod	495 in.^{3}	220 in.^{3}
Max. Comp. Stress	4,500 p.s.i.	6,430 p.s.i.
Max. Flex. Stress	7,550 p.s.i.	11,300 p.s.i.
Max. Comb. Stress	12,050 p.s.i.	17,730 p.s.i.
Weight	1,488 lbs.	1,510 lbs.

Weight comparisons between the cast steel, welded and cast steel, and the total welded arms are given below. A computed weight is the best information on the cast arm but the other weights were actually taken on a scale to make the data as accurate as possible. Costs are also listed based upon bid prices in vogue in 1935 for the cast steel and for the welded and cast steel arms. The 1942 costs for the improved arm were conscientiously kept as a matter of record. Emphasis should be given to the fact that a cheap part that fails within five years is not as economical as a well designed, durable, but more expensive part.

Type of Arm	Wt. in Lbs.	Cost in Place
Cast Steel (1935)	1350	$266.50
Welded and Cast Steel (1936)	1510	231.60
All Welded (1942)	1488	458.60

The actual saving in making an all welded sector arm is more real than apparent. To make one cast steel arm would have meant that an expensive pattern must be made first, a priorities rating must be obtained from Washington, D.C., a foundry would have to be located that was not jammed with war orders and could make the part within a reasonable time. Experience along this line indicates a minimum delay of 30 days for a casting and a 1942 cost ranging up to $800. Actually, it would be problematical if the work would be done at all since all shops on the West Coast are contributing their facilities to the war effort.

Any delay in traffic through the lock caused by a breakdown of operating machinery means a serious loss to shippers. This loss cannot be estimated but it suffices to say that dependability of machines is of the utmost importance. It is common knowledge that rolled plates are more dependable in strength than castings unless elaborate and time consuming methods of examination are employed. Time could not be wasted in this instance.

Thoughtful arc welding not only increased the strength of this machine part designed and fabricated under the author's supervision but also enhanced the appearance and reduced the time required for making the piece because materials were on hand. The arm has been in service for three months and under trials that sheared certain pins in other parts of the miter gate machinery, showed no distress or signs of failure. This actual, not hypothetical, case of applying modern design and technique of arc welding has solved another problem.

Chapter XVI—Arc Welded Tubular Aircraft Jigs

By Richard H. Holmes,

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Richard H. Holmes

Subject Matter: Arc welded tubular aircraft jigs make for cheaper and better production. How the production design engineer facilitates the design of parts and assemblies for easy tooling is first described, followed by a description of jigs and fixtures for the center wing panel of a large transport plane. Arc welded tubular steel affords the best, most rigid, and cheapest construction of jigs. The material is also easiest to obtain. Savings of 43–66% in labor cost are shown as compared with bolt and dowel construction on structural steel. The total saving amounts to $500 per jig and would total nearly a million dollars annually for the industry. There would also be few accidents to workmen.

The key to successful production schedules in aircraft plants depends to a large degree on tooling. Aeronautical engineering has made rapid progress in the past ten years as a result of the many schools which have been established and the establishment of various research laboratories, but aircraft tooling has not been given the attention it deserves. No tooling schools of any consequence have been established. To the writer's knowledge no books on aircraft tooling, jigs, and fixtures of real merit have been written.

Development—One reason for this is that airplanes were not manufactured on a really productive scale, and therefore extensive tooling was never thought to be necessary. However, in the past year or more, the situation in aircraft production has changed. To cope with the current accelerated war production for aircraft and to compete in the vast and lucrative transport markets of the future, aircraft tooling is expanding and developing rapidly.

It will, therefore, be the purpose of this article to show how arc welded aircraft tubular jigs have, through careful planning, proved themselves in affording better production in the construction of Curtiss transports, over other types of jig construction.

In an endeavour to represent the article in an intelligent, clear and interesting manner, the writer shall begin with a brief discussion on how the production design engineer facilitates the design of parts and assemblies for easy and simple tooling. How the production design engineer coordinates and cooperates with planning and tooling departments in selecting the type of jig and fixture needed, the method of constructing the jig and the material required; how in conjunction with the above the planner will route or plan the part or assemblies to be fabricated through the plant and how they shall be handled on the jigs; how the tool designer will begin and develop the design handed down to him from decisions made by the engineering and planning departments; how the shop when finally receiving the jig and fixture design, begins manufacturing on it. Then finally how the results

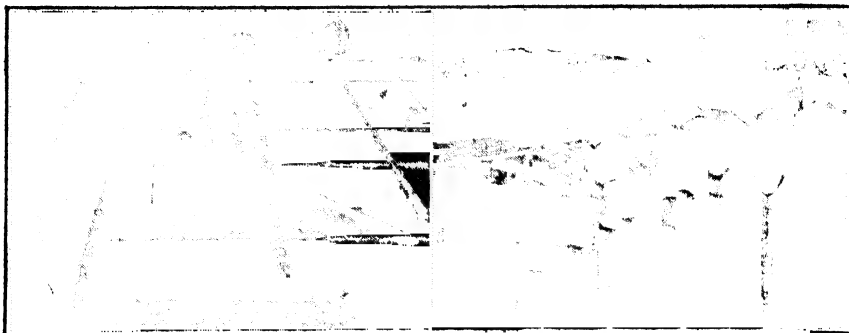



Fig. 1, (left). Ends of casing torch cut for base of fixture. Fig. 2, (right). Casing torch cut for center panel of main assembly fixture.

through ease of manufacture and costs analysis prove that the decisions and designs were correct.

Coordination—In the Curtiss aircraft plants the primary purpose of the production design engineer is to be responsible for the parts or assemblies being designed to obtain maximum shop production. Experience has shown that about 90 per cent of the layout engineers do not have a very good conception of where a part goes to be made, how it is to be made, what tools are necessary to make it and how much it will cost to make it. The production design engineer and staff has usually had at least two years of shop experience in either tool design or production planning besides five to six years of actual layout and design in the engineering department.

In addition they have a well-rounded education from some reputable engineering college. With this knowledge and experience they are constantly observing the process and procedure of the layout engineer in groups such as fuselage, wings, nacelles, power plant, etc., and making suggestions to him to improve his design. Assemblies that orginally started with eight or ten pieces are simplified to three or four. Further advice may provide bend radii to be made greater, and tolerances to be made more lenient, large parts to be broken down in order to facilitate tooling and manufacturing. Sheet metal parts are designed to meet requirements for blanking die, hydro-press or drop hammer operations. Proper materials to afford the greatest strength

Fig. 3, (left). Framework, center panel, main assembly fixture. Fig. 4, (right). Another view of framework center panel main assembly fixture.

with the lightest weight are continually being recommended by the production design engineer.

Since alloy aluminum may be purchased in a soft or hard condition, it is highly desirable to design and make parts from stock in the hard condition wherever possible. Soft stock, after forming operations, requires heat treatment to bring up to the tensile strength needed, and heat treatment is always an expensive operation in aircraft manufacture. For instance, the parts must go to the ovens, then be allowed to cool, then back to the forming operation for restrike in order to eliminate the warpage caused by heat treatment. All this sometimes requires special fixtures. These fixtures should be minimized by designing the part properly and calling out the proper material.

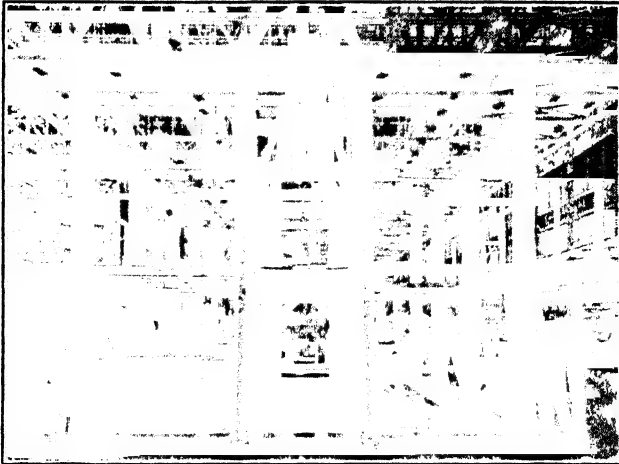



Fig. 5. Fixtures bolted and doweled to attaching faces welded to tubes.

Probably one of the most important duties of the production design engineer is to see that parts are standardized as much as possible and that they are designed to be interchangeable with left and right hand conditions on the airplane. From the foregoing it should readily be observed then that the design of a part must be considered with relation to the design of the tool which is to hold it in place. Simplification and more simplification of design is essential so that tooling can be made simple and fool-proof.

In order to assure himself on signed approvals made on engineering layouts, detail and assembly drawings, the production engineer will coordinate the problem with the production planning department. Through this coordination and cooperation between departments, the design is "frozen" on the engineering layout board and costly changes and delays are thereby minimized before they reach the shop. To give a brief and clear understanding of the planning department it will be wise to describe the function of the planners. These men plan the intricate routing of the part through the plant. That is, they write operation sheets showing which department is to start making the part, what loft templates will be needed to make the pattern, what machines and tools will be needed, what type of processing will be used on the parts, what time or priority is essential in each department for the part to be ready at the correct time, etc. As an illustration refer to operation sheets I, II and III.

OPERATION SHEET I

9-22-41				20-020-1059-2 L/R
1 10-16-41ACM	-020	Assembly		
2 11-1 [illegible]	Rib Assem.			
3 12-10-41ACM	ACM			
	FJK			

TOTAL	TIME	DEPT	OP	OPERATION NAME (4)	MACHINE	TOOL NUMBER	TOOL NAME
		19	1	Place following parts in jig & drill holes		20-020-1059-2-T61L	
						20-020-1059-2-T61R	
				20-020-1059-4 L/R		box jig	
				" " -5 L/R		P-30051 Drill table	
				" " -6 L/R			
				" " -8 L/R			
				" " -9 L/R			
				" " -10 L/R			
				XXXXXXXXXXXXXXXXX			
				" " -12			
				" " -14A L/R			
				" " -16A L/R			
				" " -18A L/R			
				" " -20A L/R			
				" " -22A L/R			
				" " -24A L/R			
				" " -38			
				20-020-1168-3 L/R			
				20-020-1004-7 L/R			
				" " -9 L/R			
				" " -43 L/R			
				20-020-1006-17 XXX (L.H.)			
				20-020-1006-58 (R.H.)			
		19	2	Remove parts & burr			
		19	3	Place in fixture & rivet		20-020-1059-2-T71L	
						20-020-1059-2-T71R	
						major assem fixture	
		19	4	Drill "Rib to spar" attachment holes at 30% & 70% spar locations		20-020-1059-2-T71L	
						20-020-1059-2-T71R	
		19	4P	DRILL STGR. CLIP HOLES			
		19	5	Remove from fixture & finish rivet where nec.		P-30052 Rivet table	
		13	6	Inspection (3)			
				3--ADD OPER 4P			
				1--REMOVED -11 FROM OPER #1	2--ADDED -58RH, MADE -17LH		
		12	6C	CLEAN RIVETS & BARE SPOTS FOR PAINTING- BOTH SIDES			
		12	7	SPRAY 1 COAT PRIMER ON RIVETS & BARE SPOTS--BOTH SIDES SPRAY 1 COAT ALUMINIZED PRIMER-BOTH SIDES			
		13	8	INSPECT OPER 6C, 7			
		19	9	ASSEMBLE			
				-3-			
					20-020-1059-2-T11 MASTER TEMP		
					20-020-1059-2-T15-1L JIG TEMP		
					20-020-1059-2-T70-1-L MASTER DRILL PLATE		
					20-020-1059-2-T15-2 JIG TEMP		
					20-020-1059-2-T70-2 MASTER DRILL PLATE		
					20-020-1059-2-T15-1-R JIG TEMP		
					20-020-1059-2-T70-1-R MASTER DRILL PLATE		
				2--ADDED OPER 6C, RVSD. OPER 7			

ON ASSEM 20-020-1000-1 CLASS SHEETS 2 NO 2 PART NO 20-020-1059-2L/R

OPERATION SHEET II.

9-16-41 / 1-6-42ACM | 020 | .051" Alclad 24SO approx 61" x 13" | 20-020-1059-4 L/R

WSD | SPEC 11067-type I

ACM

FK

(10)

TOTAL	TIME	DEPT	OP	OPERATION NAME	MACHINE	TOOL NUMBER	TOOL NAME
		17	1	Drill locating holes & fasten stock to table	router	(32)20-020-1059-4-T12 [illegible] temp.	
		17	2	Route complete	"	(31)20-020-1059-4-T22 router form	
		17	3	Burr edges	burr whl.		
		17	4	~~Stack & drill #41~~ AND 1/4" HOLES	~~s.s.drill~~	~~20-020-1059-4-T12~~	
		17	5	Burr holes			
		17	6	Form	hyd.press	20-020-1059-4-T31L form block (steel)	
		~~17~~	~~7~~	~~Stamp part no.~~		~~(31)20-020-1059-4-T31R~~ form block(steel)	
		13	8	Inspection (8)			
		25	9	Rework as necessary			
		~~13~~	~~10~~	~~Inspection~~			
		5	11	Heat treat			
		25	12	Line up			
		~~13~~	~~13~~	~~Inspection (4)~~			
		8	14	Chromic acid dip			
		13	15	Inspection		20-020-1059-4-T16 form block temp	
		~~12~~	~~16~~	~~Finish per spec.~~			
		13	17	Inspection			
		19	18	Assemble			
				-5- 1--REVISED OPER #4			

ON ASSEM 20-020-1059-2 L/R | SHEET | 2 -020-1059-4 L/

The planners also give the orders for the type and amount of jigs and fixtures to be made. Further recommendations to simplify the part or assemblies after a more detailed investigation by the planner may be made here. This is called a "Planning Request for Engineering Change" and is submitted in writing to the production engineer for consideration.

Design—The writer realizes that to cover thoroughly the large scope of engineering, planning, tool design and shop plans, and preparations in order to make jigs and fixtures for an entire airplane, would be an enormous task. It would take more words and illustrations than are normally found in a thick textbook.

However, to illustrate a condition that presents a similar method and problem on the same airplane, one should select a typical condition. The typical condition for jigs and fixtures in this case will be the center wing panel of the largest twin engine transport in the world. As has been mentioned before, the production design engineer coordinates with the planning and tool design department during and after the conception of the design. After a few conferences held between key personnel of the engineering, planning and tool design departments, it was decided to build the panel-trailing edge down for the following reasons:

(a) Minimum amount of jig and fixtures are removed in extracting the wing vertically.

(b) Ease of extraction is further induced because of the wing's natural taper toward the trailing edge.

OPERATION SHEET III

Changes	Order No.	Amount and description material ordered	Part No.
9-16-41 1 1-6-42ACM	020	.051" ALCLAD 24SO APPROX 14" X 81"	20-020-1168-3 L/R

Part name: WEB — Spec 11067 1

ACM — JCB

Total	Time	Dept	Op	Operation Name	Machine	Tool Number	Tool Name
		17	1	DRILL LOC. HOLES & FASTEN STOCK TO TABLE	ROUTER	20-020-1168-3-T12	BLANKING TEMP
		17	2	ROUTE COMPLETE	ROUTER	20-020-1168-3-T22	ROUTER FORM
		17	3	BURR EDGES			
		17	4	STACK & DRILL	S.A.DRILL	20-020-1168-3-T12	
		17	5	BURR HOLES			
		17	6	FORM	HYD.PRESS	20-020-1168-3-T31L	FORM BLCK (STEEL
		17	7	STAMP PART NO.			
		13	8	INSPECTION (8)			
		25	9	REWORK AS NECESSARY			
		13	10	INSPECTION			
		5	11	HEAT TREAT			
		25	12	LINE UP			
		13	13	INSPECTION (4)			
		8	14	CHROMIC ACID DIP			
		13	15	INSPECTION		20-020-1168-3-T16	FORM BLOCK TEMP
		12	16	FINISH PER SPEC.			
		13	17	INSPECTION			
		19	18	ASSEMBLE			
				XSX -3-			
				--RVSD OPER 4			

On Assem 20-020-1059-2 L/R Class Sheets 1 No 1 Part No 20-020-1168-3 L/R

(c) Approximately five feet of height may be saved on the jig structure because the leading edge assembly shall be assembled on a sub-assembly jig and will require no further jigging on the main wing panel jig.

(d) Key held fixture points, such as flap supports and aileron hinge brackets are close to the floor where rigidity and working facilities are maximum.

(e) Low jig structures mean less left for workmen to raise equipment.

The tool designers working under the direction of the planning department took the foregoing decisions and proceeded to thoroughly visualize the parts and assemblies to be held. Tool orders were submitted (Refer to "Tool Order") and the design of the jig and fixtures began. After considerable

TOOL ORDER

Part name			Part No.
2 No. Pcs.	John Doe Ord. By	447-020 Ord. By	Date 4-2-42
Tool No.	Type of Tool	Des. By	Remarks
20-020-1000	Arc Welded Tubular jig MAJOR ASSEM.	Curtiss	Design as sketched by production design engr., and planners. Consult for further info.

consultation and coordination with the writer, due to his position and previous experience in large jigs, the following basic principles in good jigging were submitted to assure accuracy and interchangeability of parts.

I, **Rigidity of Structure**—a) Minimizing of deflection by using heavy steel members such as tubes and channels for main frames.

II, **Accuracy**—a), Adjustable pads to correct jigs deformations and deflections; b), "Foolproof" in order that inexperienced men may not jig parts incorrectly. c), Main construction to be adapted for use in future ship construction; d), Jig construction to readily take removable wheels, so that it may be rolled and relocated at any time.

III, **Accessibility to Part**—a), Ability to retract fixture so that part may be readily removed. b), Clearances for rivet guns and tools; c), Opening for men to get through: d), Ease of assembling parts. e), Sharp edges and protruding parts such as bolt heads or clamps to be minimized or protected in order to afford safety to workmen.

IV, **Accessories**—a), Platforms of ample size for men and material; b), Benches handy for keeping tool boxes, grinders, small vises, drill machines, etc. c), Electrical and air plug outlets available every 30-square feet. d), Convenient frames for placing large blueprints.

V, **Location**—a), Jig structure to be located where elevated cranes may extract part vertically out of jig if necessary. b), Located near sub-assembly jigs and main tool bins so that greatest amount of time is saved in transfer of articles.

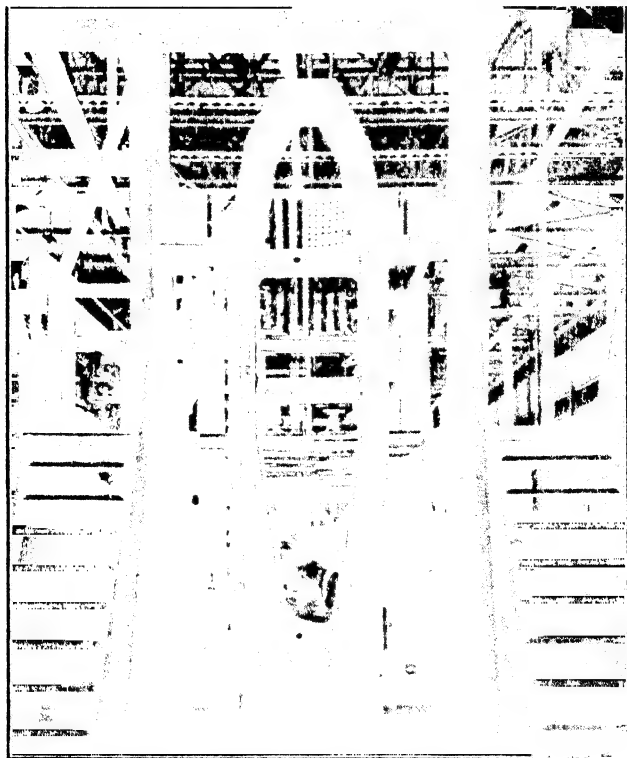



Fig. 8. Setting locating casting in fixture.

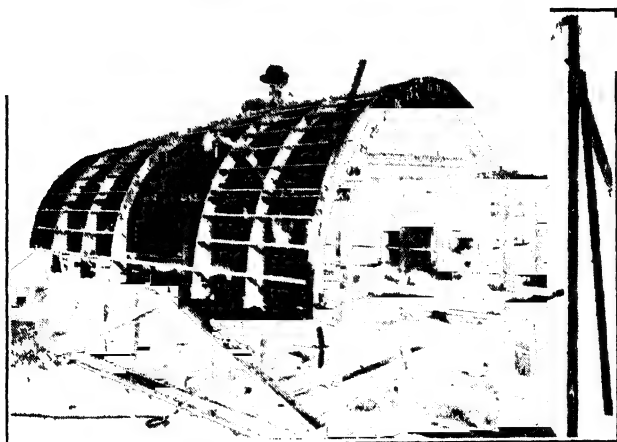



Fig. 7. Jig using structural steel numbers.

To further enlarge upon the reasons for the selection of tubing or casing and the method of jig fabrication in Item I, "Rigidity of Structure" the following shall be observed.

1. Tubular structure affords rigidity in all directions.

a), The strength and rigidity of a steel tube is better in torque and compression than any other section of equivalent area.

b), Rigidity is most essential in jigs and fixtures in order to minimize deflections.

c), Tubes are very suitable for both large and small jigs and fixtures because of the features shown in (a).

2. Tubes or Casing are cheap and easy to procure.

a), Used oil well casings obtained from Pennsylvania, Kansas, Illinois, Oklahoma, and Texas oil fields afford a ready market.

b), No government priority rating was necessary, as is the case in obtaining structural steel.

3. It was believed that to obtain the most effective rigidity at the joints that arc welding would give the best results.

a), Arc welding was thought to offer the quickest and cheapest type of joints.

The advantages of bolting and doweling structural steel over arc welding tubular structure were presented as follows:

1, Ease of assembling, particularly to a shop used to the method.

2, Maintenance of accuracy at all stages of assembling.

3, Ease of dismantling for relocation.

a) Aircraft plants are continually changing the interior plant layout to accommodate new models.

b) In case of rework bolt and dowel holes can be redrilled or enlarged.

Fabrication—There is an old Chinese proverb which states, "A picture is worth a thousand words." To take advantage of this wise old adage is to refer to the accompanying pictures and brief description for observation of design and method of fabrication.

The foundation or base of the jig is composed of ten inch casing with about $\frac{5}{16}$-inch wall thickness, to which adjustment pads are attached. Due

to constant vibration induced by rivet guns and impact of mens' feet, large jigs have a tendency to get out of line. Severe variation of temperature can also cause distortion. On the west coast, Aircraft Plants close to the shore line encounter difficulty with ocean tides moving the floor underneath. To check misalignment, a bench mark on a column firmly imbedded in the ground is swung by spirit level and scribed on various uprights of the jig. Once or twice a month the elevation of the scribed line is checked with the bench mark. If any deviation occurs, the jig is lowered or raised as the case may be. Adjustment pads are therefore, very necessary.

Construction—In photographs, (Figs. 1 and 2), it may be noted that the ends of the casing have been accurately torch-cut by making use of a loft developed template. Punch pricks are marked around the edges, the templates removed and the torch applied, extremely jagged edges were rough-filed or chipped off. All members were therefore productively fabricated for easy assembling. Vertical members were raised into position by overhead monorail and hoist and checked by plumb-bob. Tack welds were first applied to assure proper alignment. Tubes depending on their size were given two or three beads, to assure penetration, since rigidity rather than tensile strength was required. Care, however, had to be exercised in not burning through pitted or rusty casings as their wall thicknesses varied from .134 to .25. The weldable qualities of the casings were good since, on an average, the chemical analysis was as follows:

C	Mn	P	S	Si
.025	1.48	.016	.018	.06

Tensile strength about 90,000 pounds per square inch.

Welding rods giving the best results were $\frac{3}{16}$-inch to $\frac{5}{32}$-inch diameter with tensile strength also about 90,000 pounds per square inch.

After the vertical members were secured, tie in braces and working

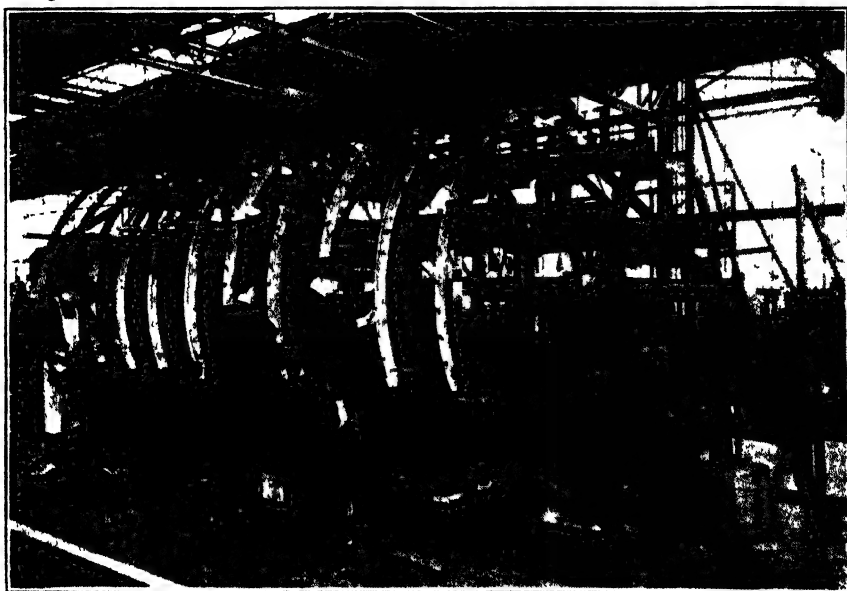



Fig. 8. A second jig using structural steel numbers.

platform frames were added. (Refer to Figs. 3 and 4). The base of the jig and platforms were covered with wooden flooring to provide easy access for workmen.

Approximately 90 per cent of the wing panel jig is composed of tubular structure. Where pads or fixtures had to be located, steel channels, providing three attaching faces, were welded to the tubes. Steel machined fixtures were bolted and dowled to these faces, (Refer to Figs. 5 and 6). Accuracy of plus or minus .01-inch in five feet was assured by the use of transit and scales marked in hundredths of an inch. Wherever greater accuracy was desired micrometers were used.

At each end of jig which was built to hold two panels, large arc welded castings with the approximate contour of the wing were secured as may be observed in photograph Fig. 6. Bolt holes spread about eight inches on center provided means for bolting the panel attach angle. The attach angle is of extruded aluminum alloy and is used to join the outer wing panel to the center panel.

Comparative Costs—The purpose of this article has been primarily to show that arc welded tubular construction is the best for aircraft jigs. To best prove the advantages is to compare construction costs of other jigs used on this same airplane. Considerable investigation and experiments were conducted and the following comparative sectional areas, weights and costs of material used is submitted. (Refer to pictures Figs. 7, 8 and 9 for jigs using structural steel numbers).

Tubular Material

Actual Dia. of Tube Used Inches	Wall Thickness Inches	Sec. Area Sq. Inches	Moment of Inertia All Axis Inches⁴	Wt. per Ft. Lbs.	Cost per Ft. Dollars	Cost per PD. Dollars	Maximum Weldable Periphery Inches
4.00	.134	1.65	3.04	5.6	$0.25	$0.045	14
5.00	.152	2.38	6.81	7.9	0.42	.053	17
6.00	.164	2.91	12.9	10.2	0.50	.049	20
8.00	.186	4.65	35.2	15.8	1.00	.064	26
10.75	.250	8.25	113.8	28.0	1.50	.048	37

Structural Steel Material

Size of Struc. Steel Used Inches	Thickness Inches	Sec. Area Sq. Inches	Moment of Inertia on Best Axis Inches⁴	Wt. per Ft. Lbs.	Cost per Ft. Dollars	Cost per PD. Dollars
*3½x3½ L	.25	1.69	2.0	5.8	$0.17	$0.030
*4 x4 L	.312	2.40	3.7	8.2	0.25	.033
*4 x4 L	.437	3.31	5.0	11.3	0.40	.035
6 x6 H	.312	4.59	30.1	15.5	0.54	.035
10 x2⅝ L	.55	8.80	103.0	30.0	1.14	.038

*Please note—to obtain the same comparative rigidity, two members had to be used.

Average Arc Welding Cost On Tubes

Operation for One Joint	Time in Minutes 4" Dia.	6" Dia.	8" Dia.	10¾" Dia.
1. Layout casing with template and center punch radius	1.50	1.85	2.05	2.25
2. Acetylene cut to length and contour as marked	1.25	2.50	3.75	5.00
3. Fit—remove and trim, hammer off scale	1.40	2.50	3.50	4.00
4. Tack spots and hammer off scale	1.00	1.90	2.20	2.40
5. Weld 1 bead—hammer off scale and wire brush	4.00	7.90	10.90	12.90
Weld 2nd bead—hammer off scale and wire brush			5.00	6.40
Weld 3rd bead—hammer off scale and wire brush				6.40
Total Actual Time	9.15	16.65	27.40	39.35
Labor Cost Per Joint in Dollars (Torch Cutter or Welder) @ $1.10 per hr.)	.17	.33	.50	.72

Average Bolt and Dowel Cost On Structural Steel

Operation for One Joint	Sizes	Time in Minutes 3½x3½ L	4x4 L	6x6 L	10x2⅝ L
1. Layout and center punch angle of cut-off		(1.00	1.25)	2.00	2.05
2. Acetylene to length as marked		(2.50	4.00)	5.00	6.10
3. Chip off rough edges power trim, 2 pieces		(.75	1.25)	1.50	1.58
4. Clamp, drill, and ream 2⅜ dia. dowels		(15.00	20.00)	19.00	30.00
5. Drill for 1⅜ dia. bolt		5.00	8.00		
6. Drill for 2½ dia. bolt				16.00	21.00
7. Insert bolt power tighten nut		1.00	1.00	2.00	2.00
Total Actual Time		25.25	35.50	45.50	62.73
Labor Cost Per Joint in Dollars (Structural Man @ $1.20 per hr.)		.51	.73	.91	1.26
Labor Cost Per Weld Joint in Dollars		.17	.33	.50	.72
Savings per joint		.34	.40	.41	.54
% Saving of joint in dollars		66%	55%	45%	43%

Note:

1. 4-inch diameter tube requires 2 tacks, 6-inch diameter, 8-inch diameter, 10-inch diameter requires 4 tacks.
2. For thickness and sectional areas of members refer to table "Structural Steel Materials."
3. Welding rod cost versus bolts and nuts were considered about equal and therefore are not included in the estimate.
4. Overhead for both types of jigs considered the same.

The two types of jig construction discussed could have been further simplified in design had more time been allocated. That is if more stress analysis had been applied members could have been lightened and in some cases omitted. In the original design weight of structure was not considered. Rigidity in members and joints was the object. Although no accurate figures are available, indications are for the same rigidity—approximately 4½ pounds of structural steel is necessary for each pound of airplane against approximately 3 pounds of tubular steel for each pound of airplane. From the foregoing, to illustrate how the weight and cost of a jig frame would compare for the wing center panel weighing 3500 pounds, the following interesting figures are submitted.

Arc Welded Tubular Jig										Bolted and Dowled Structural Steel Jig					
Part	Length in Ft.	No. Req'd	Length Req'd in Ft.	Tube Size Dia.	Wt. per Ft.	Wt. in Lbs.	Cost of Mat. in Dollars	No. of Joints	Cost of Joints	Size of Member	Wt. per Ft.	Wt. in Lbs.	Cost of Mat. in Dollars	No. of Joints	Cost of Joints
A	16	8	128	6	10.2	1,310		16		6" I Beam	15.5	1,980		16	
B	10	4	40	6	10.2	410		8		6" I Beam	15.5	620		8	
C	14.5	12	174	6	10.2	1,770		24		6" I Beam	15.5	2,700		24	
D	36	6	216	6	10.2	2,200		12		6" I Beam	15.5	3,360		12	
E	12	4	48	6	10.2	490		8		6" I Beam	15.5	745		8	
F	13.5	3	40	6	10.2	410		6		6" I Beam	15.5	620		6	
G	6	4	24	6	10.2	245	$3,350	8	$27	6" I Beam	15.5	370	$3,610	8	$75
H	12	8	96	4	5.6	536		16		4x4x5/16 L	8.2	785		16	
I	36	6	216	4	5.6	1,210		12		4x4x5/16 L	8.2	1,770		12	
J	3	8	24	4	5.6	134		8		4x4x5/16 L	8.2	197		8	
K	12.5	6	75	4	5.6	420		12		4x4x5/16 L	8.2	60		12	
L	14.5	6	87	4	5.6	487	1,255	12	10	4x4x5/16 L	8.2	70	950	12	44
Total						9,622	$4,605	142	$37			13,277	$4,560	142	$119
Plus 8% for other material and joints						770	367		3	Plus 20% for other material joints and expense for handling extra weight		2,650	910		24
Grand Total						10,392	$4,972		$40			15,927	$5,470		$143
Savings in Dollars							$ 398		$103						
Percent saving in Dollars							7.3%		72%						
Total saving in Dollars							$ 501								

Fig. 9. A third jig using structural steel numbers.

Estimate of Annual Gross Savings—Although it would be very difficult to obtain accurate figures on annual savings from arc welded tubular jigs over other types of aircraft jigs, an appropriate rough estimate for the Curtiss Aircraft Co., can be submitted. From the foregoing figures it may be observed that on a contemplated transport center panel jig weighing approximately 10,000 pounds that 501 dollars were saved over a bolted and dowel structural steel jig of equivalent size, but additional weight.

On this basis five cents is saved on each pound of arc welded jig work. As has been mentioned before, approximately three pounds of tubular steel jig is required for each pound of airplane and since an average large transport will net about 28,000 pounds, one can assume about 84,000 pounds of steel for one set of main assembly jigs only. An additional amount as above will be necessary for jig structures on subassembly jigs and handling equipment or a total of 168,000 pounds for complete set of jigs for one ship.

To obtain a production schedule of four transports per day (an expected figure for 1943 in all aircraft plants making transports) eight complete sets of jigs will be at least required or a grand total of 1,344,000 pounds. (The number of jigs required is estimated through long years of experience, and is beyond the scope of this article to explain). At a saving based on five cents per pound, this amounts to an annual net saving of approximately $67,200. An annual saving is mentioned since average maximum contracts are presently being issued for 1000 to 1200 planes and that at four ships per day, the contract would be completed within the year. Thus the average life of the jigs would also be completed within this period before dismantling would become necessary for other models and contracts.

If one considers that there are at present about thirty major aircraft plants in the United States composed from ten major aircraft companies, the annual gross savings possible from using arc welded tubular jigs, in all kinds of military and commercial aircraft would run well into several hundred thousand dollars and perhaps into a million.

Social Advantages—It is thoroughly realized that jig men may state that structural steel in the way of channels, I beams and angles could be arc welded in a similar manner as is done on tubular structure. In some

cases the arc welding of structural steel jigs may be cheaper. It is also realized that tubular structure need not be welded but can be jointed with fittings although it seems a very expensive way, as illustrated in the two tables. However, the fact that arc welded tubular jigs are safest is not often realized. Structural steel jigs offer sharp edges and corners for workers to injure their heads and shins. If they are bolted, sharp or ragged edges on the bolt threads tear clothes and may cause severe cuts on limbs and hands of workmen.

Cast fittings and bolted joints offer the same safety disadvantages to workmen on tubular structure. The smooth streamline effect of tubular structure with smooth, neat, arc welded joints presents very few hazards to the workmen. In addition, due to the contoured surface of the tubes, no tool rests are afforded to the workmen as is the case of structural steel in allowing placement of wrenches, rivet hammers, and bolts, etc., which are constantly falling off and injuring people below. Tubular arc welded joints discourage any accumulation of waste, shavings, dirt and grease and are thus easier to keep clean over structural steel jigs.

On a recent rough investigation conducted by the author, in the Buffalo Curtiss plants, the following data is submitted. It should be noted the investigation was conducted over a three months period with about the same number of men on each case during the same daylight hours.

On an average, for every 10,000 man hours applied on structural steel jigs, including fabrication, there was a loss of approximately 200 man hours attributed to head, hand and other injuries incurred on the jig. For every 10,000 man hours applied on arc welded tubular jigs including fabrication there was a loss of approximately 60 man hours attributed to head, hand and other injuries incurred on the jig. A saving of 140 man hours in every ten thousand is considerable saving in the course of a year to any company.

Computing on the basis of 1,000,000 man hours per year at a dollar an hour average per man, the saving is $14,000.

Conclusions—In concluding, a summarization of points proved is submitted.

1. Through careful and expeditious design in production engineering the jigs and fixtures necessary to make the part or parts can be simplified.

2. Through close coordination and cooperation between engineering, planning, and tool design the proper decisions can be made on the design, material and kind of joints to be incorporated in the jigs and fixtures.

3. That the most favorable selection of framework material in jigs for rigidity and ready market is tubular steel.

4. That to assure rigidity at the joints and cheapness of fabrication, arc welding is by far the best over the other types of joints.

5. That if more careful stress analysis is made on jig designs that lighter members could be used and thereby save money on less dollars per pound on material and handling costs.

6. That arc welding of joints could be further less expensive if the weld were applied only enough to account for the amount and direction of load.

7. That the annual gross savings in the aircraft industry alone by using arc welded jig construction and the social advantages gained therefrom would amount to over a million dollars.

8. That arc welded tubular jig construction is making for cheaper and better production today and that it will continue to make even cheaper and better production tomorrow.

Chapter XVII—Tilting Table for Armor Plate Production

By MARK ARONSON, B. S. AND EDWARD A. FOEHL, B. S.,
Research Engineer and Naval Architect, respectively, of United States Navy Yard, Philadelphia, Pa.

Mark Aronson

Subject Matter: The design and construction of a tilting table for efficient heavy plate production. The extensive machining peculiar to this work necessitated a tilting table on which to fasten the plate for planing. The tables could not be purchased and had to be built with exacting requirements as to precision, deflection under load, etc. The table eliminates the former practice of resetting the massive plate for each new cut. The top surface is 41- by 15-feet. The table consists of 332 pieces of steel plate welded into a unit weighing 82,534 pounds. The plate is 1- to 4-inches thick. Only arc welding was considered for the work, because of the known advantage in cost, speed, etc. The table was stress relieved after welding.

Edward A. Foehl

This paper embraces a subject of highly confidential character—the production of finished armor plate for the protection of naval vessels.

The authors, designers of tilting table, not only as present members of the navy department, but also as patriotic citizens, are deeply appreciative of their responsibility not to betray any confidences which might aid the enemy.

Several weeks before the unfortunate Pearl Harbor catastrophe, the authors, with official approval, started the preparation of this paper. The less stringent restrictions concerning the disclosure of naval information at that time would have necessitated only the elimination from this paper of fundamental details of the armor plate itself, such as composition, physical properties, maximum size, particularly the thickness of the largest plates, intimate details of machining and fabrication, as well as method of assembly and attachment on ship to assure greatest resistance to impact forces. The disclosure of the welding details of the tilting table itself would not be materially restricted.

Since the advent of war however, further restrictions have been placed by the navy department, so that further deletion of material became necessary. Although the authors could still furnish welding information, the story in connection with the tilting table might be less interesting due to the necessary omission of ingenious operating features, as well as figures of actual costs and savings effected by the 100 per cent arc welded type of construction.

Other interesting information originally planned to include but necessarily deleted concern the elevating and locking mechanism at any desired angular position of the table, and the devices for resisting the longitudinal, transverse, and vertical thrust resulting from the heavy cuts of the planer

tools; all of which are components that go to make up the entire tilting table assembly.

It is not difficult to understand why the above intimate details cannot be released at this time. An enemy power would have most to gain should complete design details be disclosed.

Sufficient calculations, mathematical treatment, and stress diagrams entering into the theory and design of the table are included to familiarize one with the technical approach to the design problem; chiefly to the extremely important deflection factor that entered into the design due to the close tolerances of the machining operations which had to be met.

Acknowledgment—With grateful appreciation, the authors acknowledge the cooperation and permission received from Rear Admiral A. J. Chantry, industrial manager, and Captain T. L. Schumacher, design superintendent of the Philadelphia Navy Yard without which this paper and its entrance in the James F. Lincoln Foundation Award Program would not be possible.

The authors also wish to acknowledge the many courtesies extended by Captain W. C. Wade, shop superintendent, including the use of negatives of the reproduction of the official photographs herein contained.

The authors wish to thank Mr. R. B. Luchars, President of the Industrial Press, publishers of Machinery, for permission to use illustrative material taken from the special issue of November 1941, which was devoted to the navy's war effort, and which featured the subject matter of this paper.

Our country's geographical position makes the navy's battle fleet, augmented by its air arm, our first line of defense and instrument of offense. Our navy's task is to command the sea; and the best way it can do so is to be superior to the enemy in every tactical form. Whether the sea encompasses one ocean or more, the fundamental mission remains unchanged.

The main fighting strength of our combatant surface fleet contains

Fig. 1. View of tilting table.

"strength" ships which combine force to overcome the enemy with protection to secure time to exert that force, and "speed" ships whose attack is comparatively light in force, but either so quickly delivered or from so favorable a point that the enemy lacks time to develop his resistance and so to absorb the attack.

Ships must be able to take, as well as deliver, if they expect to survive long in the line of battle. The combination of strength and endurance in attack is reached to the greatest extent in battleships. They represent the most powerful embodiment of combatant strength. Our floating fortresses must be so armed and protected as to be able to meet opposing battle fleets on more than equal terms. Not only must they carry the largest of guns, but they must possess the highest degree of protection.

A battleship is defended by protection in two ways—namely, by armor against projectiles and other explosive attacks, and by compartmentation against invasion by water. The weight of armor plate in a battleship is proportionately higher in percentage of displacement than in any other type of naval vessel.

Most recent experience dictates that the modern battleship must be able to resist not only the oldest form of attack, artillery fire, chiefly aimed at the upper structure and crew, but also explosive shells including deck bombs and torpedoes dropped by fliers, as well as torpedoes released by submarines against the underwater body of the ship.

To satisfy the necessary protection to a battleship, the minimum requirements of armor, aside from the local protection of turrets, barbettes, conning tower, and base of smoke pipes afforded by their own armor, is a belt extending high enough above the normal load water-line to protect the buoyancy and vital military features of the ship, and extending low enough to guard against underwater hits due to naval action or rolling of the ship. Coupled with this there must be at least one protective deck located above the deepest possible load line, all to be of the greatest practical thickness of armor plate.

Since its introduction, armor has improved materially by the improvement of the hardness of its exterior face and also by the toughness of its back, which latter quality resists cracking and disintegration. During the same time, projectiles have also been improving. This contest between the efficiency of armor and projectiles appears to be non-ending.

The problem of armor plate protection has always been given most serious thought and study by the world's naval powers. Each is confronted with this problem when it contemplates the design of more formidable warships. In time of war, this vital problem becomes acute. The catastrophic destruction of warships during the past several months of war, particularly the Pearl Harbor attack, has shocked the civilized world, and intensified thought on greater protection.

The steel manufacturer must also give intensive study to the source of supply of larger armor plates; to revamp his manufacturing set-up to be able to meet the increased demands. Through his research activities he no longer has difficulty in satisfying the metallurgical and heat treating specifications, but to satisfy the demand for increased size, larger investment in steel mills and machinery is essential.

Through the cooperation of the steel producers and steel mill machinery manufacturers, and augmented by government financial assistance where necessary, the serious production problems involved in furnishing the increased size rough armor plates were solved by the steel mills.

The fabrication and machining of these massive rough plates remained

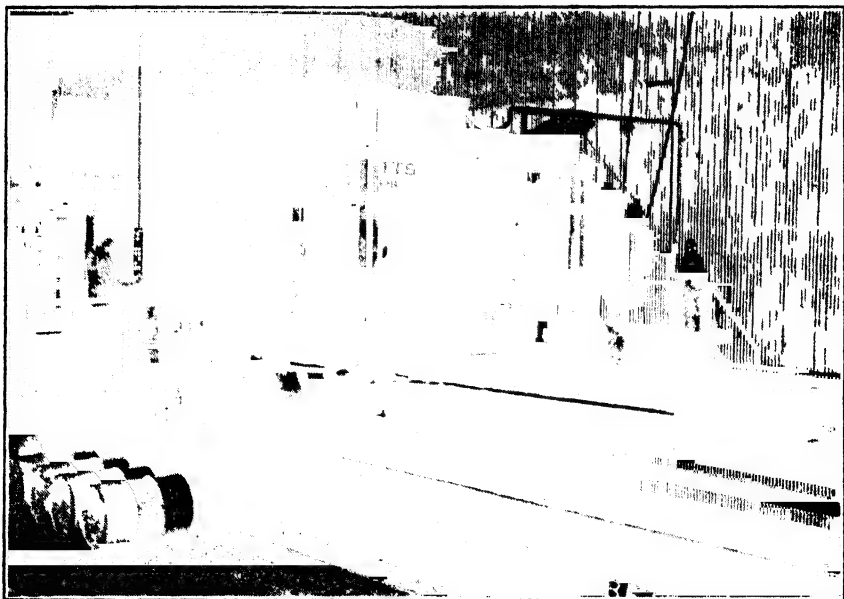



Fig. 2. Planer for armor plate.

the bottleneck awaiting solution in the program Existing equipment, formerly used in the machining operations, became obsolete when production speed became the vital issue. The navy department was obliged to purchase larger armor plate planers for the planing, cutting and machining operations

This equipment, installed within the past year at the Philadelphia Navy Yard, included two plate planers without the indispensable work tables for supporting the armor plate The conventional planer table was inefficient for this purpose and was no longer feasible for effecting the production speed demanded in machining the largest armor plates that the planers were capable of. For that reason the standardized work tables incorporated in plate planers were omitted in this planer purchase

The majority of all machine work performed on armor plate can be satisfied by plate planers The most important feature in planing is the setting-up of the work; planer tools differing little in their general design from those used for the cutting purposes in other machine tools The increased speed of planing, which has reduced the actual cutting time to a remarkable degree in many cases, makes it all the more necessary to reduce the handling time as much as possible The massive size and weight of armor plates intensify their setting-up problem, this work heretofore consumed precious time and presented a bottleneck condition in the fabrication of the finished armor plates for installation on the ships

After serious thought and study it was decided that the extensive machining operations peculiar to armor plate necessitated a tilting table. This most essential fixture for each planer could not be commercially obtained The plate-planer manufacturers, as well as other large machinery manufacturers solicited had no precedents or experience to follow in the design and construction of such a desired fixture to satisfy the exacting demands of the navy department. It finally resolved itself into a design and construction problem that had to be undertaken by the navy department itself

The tilting table for each of the planers must not only possess work positioning flexibility and support the largest armor plates without distortion, but must also assume all the severe thrust conditions imposed upon it by the machining operations of the planer itself. In view of the fact that the planers are of the pit type, capable of machining the heavy deep work requiring a pit, the tilting table must also be a readily detachable fixture.

Before one can appreciate the intricate design problems in connection with the tilting table, brief information and knowledge of the characteristics of the planers might be helpful.

The two armor plate planers located at the Philadelphia Navy Yard, and one purchased for the New York Navy Yard, are believed to be the world's largest; they are all similar in size and construction. They were built by two of the country's leading machine tool builders to specifications furnished by the navy department; and each at a cost of approximately $300,000.

In order to appreciate their size, the following dimensions of each are given: Length 65-feet; width 34-feet; and height 22-feet, 6-inches approximately.

The planers are of heavy-duty type; motor driven for both longitudinal and cross planing; motors of 150 horsepower and 50 horsepower respectively, being employed. The cross-rail is 30-feet long, and the beds on which the cross-rail carriages ride are 60-feet long. Lead-screws 7½-inches in diameter operate the carriages on which the cross-rail is mounted.

Throughout the design of the tilting table for use with each planer, consideration had to be given to the essential characteristics of these planers, portions of which are shown in the photographs, Figs. 1 and 2.

These immense machine tools are designed to have capacity for accurate and rapid planing of the top, both sides, and both ends of rectangular or parallelogram-shaped armor plates. On one side of the cross rail of the planer, two heads for longitudinal planing, and on the opposite side, one head for cross edge or surface planing, are provided. Each head is also designed to travel in reverse direction. The machines are designed to perform all planing operations in original settings.

The following important requirement of accuracy is taken from the specifications of the planers:

"The machine shall produce finished work to the following limits of accuracy. The maximum error of parallelism of two sides in a horizontal plane or a variation from a straight line in a horizontal plane must not exceed 0.005-inch in 40-feet; maximum error from a true square 2-feet high by 15-feet wide must not exceed 0.001 of an inch."

These additional lines also taken from the same specifications are significant:

"The machine shall have a variable longitudinal and cross planing speed range of 15-feet up to 90-feet per minute, and a feed rate of 1/64 of an inch up to ¾ of an inch. All heads shall be capable of taking roughing cuts 3/16 of an inch feed, 1 inch deep, without excessive vibration or chatter."

Since the tilting table fixture required for each of the armor plate planers must function with its respective planer as an integrated machine tool unit, and satisfy the above exacting demands, the design problem that presented itself can best be appreciated by noting the features required to be incorporated in the tilting table which ordinarily do not readily lend themselves to precision machine work.

One of the most serious adverse conditions which had to be taken into consideration in the design of the tilting table for the precision work expected

of it, was the fact that the foundation for the table had to be independent of the foundation for the planer itself; therefore, a slight movement or set of the foundation of either could throw the tilting table out of alignment with the planer; inferior workmanship in the construction of the foundation would also affect alignment. Inasmuch as the alignment at any angular position of the fixture bears a relationship to the degree of accuracy of the work produced by the planers, the need for perfect alignment cannot be overemphasized. The table was designed with the objective of maximum rigidity and the maintenance of accurate alignment in any angular position.

The tilting table is of parallel girder design with a top working surface measuring 41-feet in length by 15-feet in width; which area can satisfy the surface over which the planer tools can travel. The overall dimensions of the complete assembly, which includes the table, are 51-feet in length by 15-feet in width. A portable section is contained in the table, which when removed, reduces the table width to 10-feet. The table is symmetrical about its transverse center-line, or trunnion. The spacing of the plates that comprise the top working surface has been arranged to conveniently accommodate all widths of armor.

The heavy and deep girder construction which supports the top working surface is cross-braced with beams, leaving no chance for springing or distortion. This type of design furnishes great strength to resist any strain which should be applied by the fastening of the heaviest of armor plates. The authors are pleased to mention that this construction, with the rigidly designed thrust-resisting devices that make up the complete assembly, have already withstood without any distortion the heaviest cuts of which the planer drive is capable.

The table pivots about a heavy center support (trunnion) with a maximum tilt angle to satisfy the machine work required on the thickest armor plates. The trunnion bearing block is bolted to a deep T-slotted transverse beam. This trunnion is readily detachable. This portability allows the fixture to be removed from its pivot point. During the tilting movement of the table, when it is being swung to the angular position desired, its ends are restrained from sidewise movement by a novel rail device. Since every unnecessary movement of the table or operator means just so much lost in output, the entire positioning operation has been made positive and rapid, thereby contributing to the reduction of handling to a minimum.

At each end of the table are four chip disposal troughs which prevent chips from piling up and wedging within the elevating apparatus. With these troughs, all chips drop down to the base of the table.

The general construction of the entire unit lends itself to heavy cuts and large output. It was designed with features to insure long life and maintained accuracy. Both tables at the Philadelphia Navy Yard have been performing beyond all expectations, working 24 hours a day, seven days a week, since their installation.

The compactness of design, with all of the operating, thrust resisting, elevating, and controlling apparatus at the ends of the table which make up the entire fixture assembly, also allows a maximum working area in the immediate vicinity of the table, and permits ready access to the many surfaces that are difficult to reach. Every practical feature for convenience and safe operation has been embodied in the design. The wisdom of such painstaking care in the design has been more than demonstrated since the tables have been placed in service.

Although these fixtures were built primarily for the most exacting

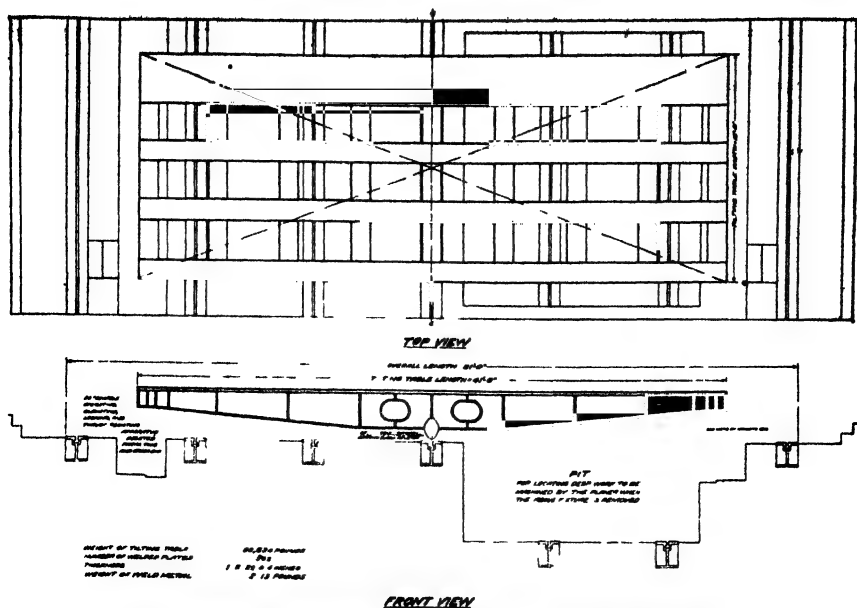



Fig. 3. General arrangement of tilting table, top and front views.

machine work on armor plate, and greately increase the output of the planers by eliminating the former objectionable and very costly practice of accurately resetting the massive plate for each new cut, they are far from single purpose however. They can be used for a number of other types of work, particularly where long straight work or tapers have to be machined. They permit the planing of long work, near the center, on the ends, in fact in any location, with the added advantage that the work piece can be rigidly supported throughout the entire length of the table.

Each table was designed with a portable section; also, the pit was incorporated in the foundation so that large work of awkward proportions or overhang may be mounted for machining, with the portable section removed.

In Figs. 3 and 4 are shown a general arrangement plan and sections. The graceful and pleasing appearance as a result of employing welding is most conspicuous.

The decision not to make use of riveting or castings, but to employ arc welding exclusively in the design and construction of this very large fixture, was not arrived at by making profound studies of each of the above methods, or their combinations. The circumstances did not warrant such a precious time-consuming procedure, and for that reason comparative figures are not available.

The authors, each of whom has had considerable design experience with structures incorporating casting, riveting and welding methods of fabrication, necessarily capitalized on this experience in their selection of 100 per cent arc welding for the method of constructing the tilting table. In carefully weighing the merits of the different methods of fabrication available, and considering expediency which played a vital role, there appeared no alternative for this particular product.

The estimated large saving in cost effected by the arc welded construc-

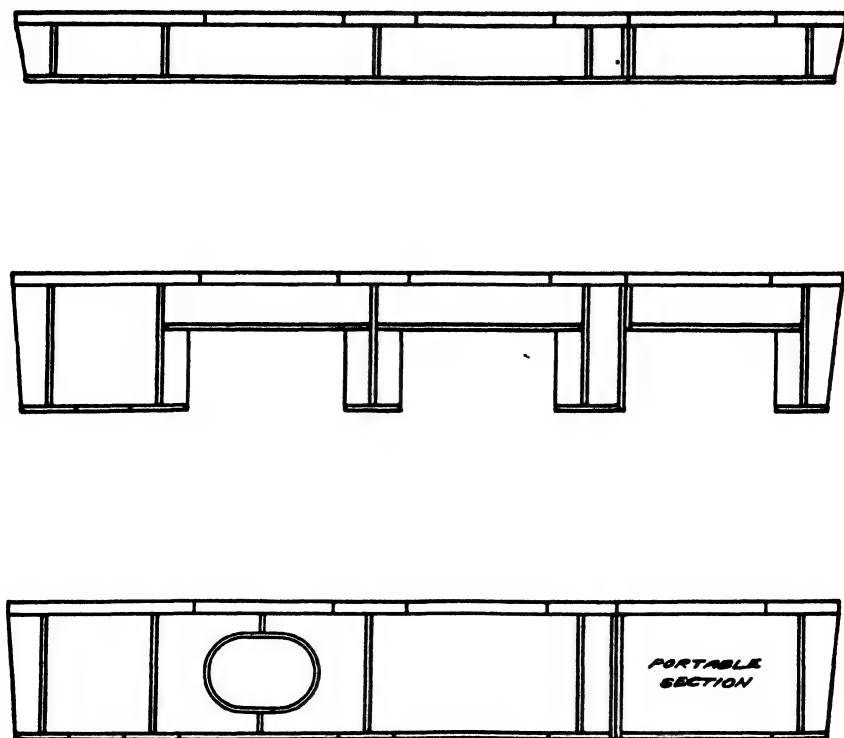



Fig. 4. Transverse sections of tilting table.

tion, and the greater speed with which the tables could be built by this method of construction, particularly by making use of stock sizes of plates, eliminated other methods when one must also consider the strategically impelling force to take advantage of speed—the massive armor plates which were piling up awaiting the successful design and construction of tilting tables essential for their machining operations.

Here was no case where one could experiment or compromise! A winner had to be picked at the outset; and welding received the honor. The consequences of failure and attendant delay in battleship completion eliminated any justification for the use of experimental methods.

The judgment, based upon the experience of the authors, particularly since the latest shielded arc type of electrode was to be used, was approved.

This faith in the dependability and economy of arc welding this novel instrument of production, which plays an indispensable part in accelerating the armament program, has been more than justified by the excellent performance of the table. With unrelenting pressure by the navy department for speed up in warship construction, the authors were never unmindful of their responsibility during the trying period of design and construction.

The non-commercial aspect that enters into the design, construction and use of the tilting table makes it difficult to measure, in terms of dollars, its value or earning power. The strategic need for this modern development also placed the question of cost in a lesser role than would be the case if these tables were manufactured for private industry. The variable factors which enter into cost accounting in different private plants and government

agencies might make cost figures misleading or non-comparable even if released by the navy department.

The following significant statement approved by the navy department, and reproduced from the description of the fixture in the November 1941 issue of "Machinery," refers to the time saving that results from the use of the tilting table; with the resultant proportionate saving in labor, cost, the high economic value of the table is evident without figures.

All cuts are taken with one set-up of the work, which effects a tremendous saving in time over the previous method, in which the work had to be shifted each time that a surface was to be machined to a different angle.

The "tremendous" saving referred to in the above tribute is of small importance compared to the earlier completion date of battleships as a result of this most efficient method of armor plate production. The production records actually made have exceeded the most optimistic expectations. Only those who are familiar with the difficulties previously encountered in the production of finished armor plate can appreciate the obstacles that had to

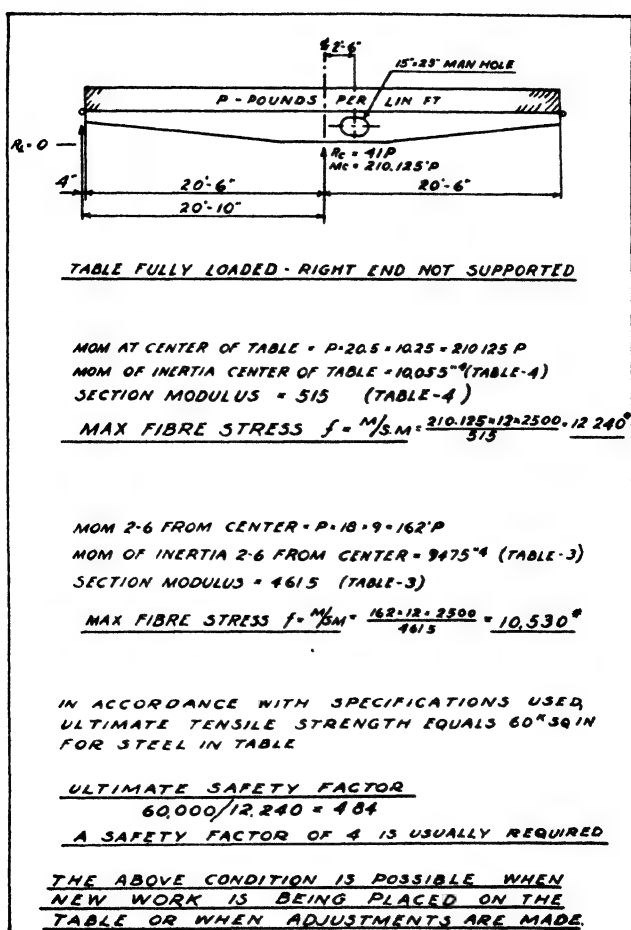



Fig. 5. Fibre stress.

be overcome in their solution, and in the creation of this unique fixture, with its capacity for the largest plates required for the latest ships.

It is a responsibility of the tilting table to insure smooth, accurate and chatter-free cutting, planing and machining during its long life as a component of the planer. It must possess the reserve strength to successfully withstand abuse brought about by any shock loads in the careless handling of gigantic plates, as well as resist distortion through undue strains encountered in fastening the plate to its top surface.

The fundamental principle of design employed in creating the table was to satisfy all structural requirements in conjunction with those peculiar to the usage of a precision machine tool, specifically a plate planer. This necessitated for the complete fixture assembly, the coordination of several branches of science and engineering, including stress analysis, strength of materials, structural, mechanical, welding, machine-tool, and if the urgent demands of the defense program for the use of the tables would have permitted, complete instrumentation features would have been incorporated, provision having been made.

An important factor that engaged attention throughout the design was the necessity for adequate clearances; also of non-interferences with the planer or with the tool itself, during usage. This placed limitations on height of table and associated operating features which, in the latter case particularly, presented some intriguing problems which had to be overcome.

In the design of the table, various conditions of loading and plate cutting were investigated; and the effect of each was studied. Investigation and analysis were also made of the table during the setting-up period, when for a short period of time the table may assume a cantilever-type structure with one end unlocked and unsupported. This condition is due to the fact that both ends are manually locked when the desired angular position of the table is reached, and it is not necessary for the locking at both ends to be simultaneous.

The fibre stress set-up during the above brief period is shown in Fig. 5.

The reversal of stress, resulting when the table was completely locked and in service assuming a three-point-suspension-type structure was given the most consideration. An analysis of this service condition follows:

Summary of Notes on Design

Physical Characteristics

Number of longitudinal girders	5
Maximum spacing, center to center	3′ 10″
Length of girders	41′ 0″
Width of table	15′ 0″
Est. Wt. of table carried by supports	82,000 lbs.
Gross area of table top	615 Sq. Ft.
Gross area of one girder (3.83′ × 48′)	159 Sq. Ft.

Loading

Dead load for table, per lin. ft. girder	500 lbs.
Plate to be machined, per lin. ft. girder	2,000 lbs.
Force due to cutting tool	22,500 lbs.

The table was designed as a continuous beam with three supports, the ends being simply supported. In actual usage, the unique locking means create fixed end supports; this treatment therefore is in the interest of safety in design.

PT	REAC	[illegible]	[illegible]	[illegible]	[illegible]	MOMENT
1	7.81 P	1 00	1 00	7.81 P	0.5 P	+ 7.31 P
2		4 00	16 00	31.24 P	8.0 P	+ 23.24 P
3		7 00	49.00	54.67 P	24.5 P	+ 30.17 P
* [illegible]		7.81	61 00	61 00 P	30.5 P	+ 30.50 P
4		10 00	100 00	78.10 P	50.0 P	+ 28.10 P
5		13 00	169 00	101.53 P	84.5 P	+ 17.03 P
6		16 00	256.00	124.96 P	128.0 P	3.04 P
7		18.50	342.25	144.49 P	171.13 P	- 26.64 P
		20 83	433.89	162.68 P	216.95 P	- 54.27 P

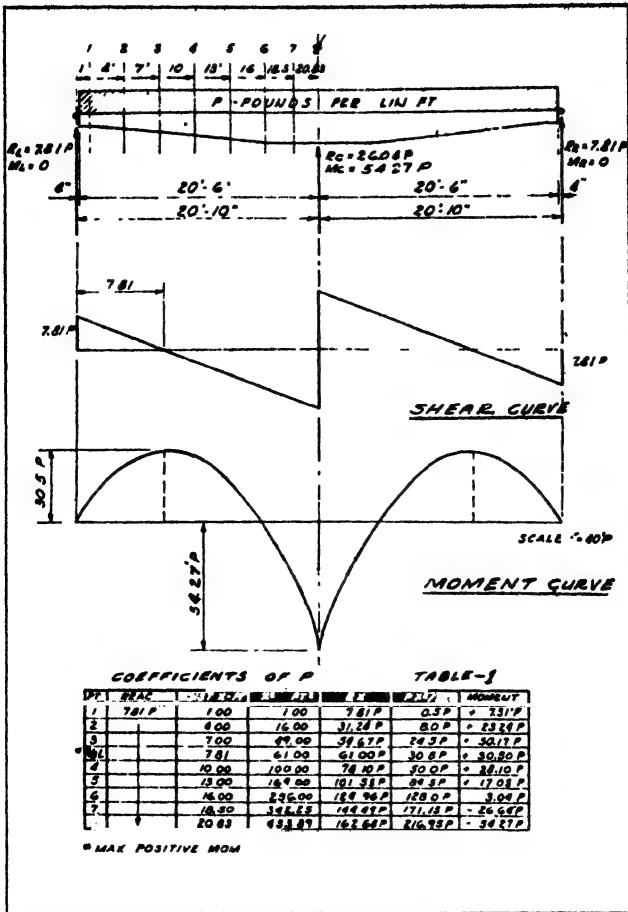



Fig. 6. Coefficients for moments in foot pounds fully loaded, supported at 3 points.

The moments and reactions were determined by the Theorem of Three Moments; although any other method such as the Slope Deflection, Moment Distribution, or Method of Elastic Weights, could have been used.

Two cases are shown here, all the supports being on the same level:

Case No. 1—The table is fully loaded.

Case No. 2—One side of the table is loaded.

Tables 1 and 2 on Figs. 6 and 7 respectively, give coefficients for the moments in terms of P foot pounds. By this method equations are derived, and substitutions are made for the actual loads at the end of the problem.

The maximum moment was found in Case No. 2, therefore the information shown by Table 2, Fig. 7, is used for computing the deflection as shown on Fig. 8.

Since the girders are not of uniform cross-section, the moments of inertia were computed at various points, namely, 1, 2, 3, etc., the location and distance from the left support are shown above the beam in each case.

Fig. 9 contains the computations for Section 7, which includes an access hole; while Section 6 is typical for other sections.

Fig. 8 records the essential computations used in calculating the deflections.

The conjugate beam method was used. One of the several other methods could have been selected but due to the similarity of the conjugate beam theory to that used for shear and moments in ordinary beams, the method used seemed preferable. All deflection calculations for beams varying moments of inertia are tedious; however the conjugate beam affords several points of check for accuracy of the computations.

To apply the conjugate beam theory, a knowledge of geometrical relations between the elastic curve and the beam are necessary.

To explain the method used, the problem as set forth on Fig. 8 will be considered.

The loading on the conjugate beam is derived from the bending moments, recorded by Table 2, Fig. 7, divided by the moment of inertia for each point. In the table, the moments were expressed in foot pounds as coefficients of P.

COEFF OF P-LEFT SPAN TABLE-2

PT	REAC-R_L	DIST X-FT	X^2-FT²	RX	$PX^2/2$	MOMENT
1	44.26P	1.00	1.00	44.26P	.5P	+41.76P
2		4.00	16.00	177.04P	40.0P	+137.04P
3		7.00	49.00	309.82P	122.5P	+187.32P
*		8.83	77.97	390.81P	194.9P	+195.91P
4		10.00	100.00	442.60P	250.0P	+192.6P
5		13.00	169.00	575.38P	422.5P	+152.88P
6		16.00	256.00	708.16P	640.0P	+68.16P
7		18.50	342.25	818.81P	855.6P	-36.87P
℄		20.83	433.89	921.94P	1084.73P	-162.79P

*MAX POSITIVE MOM

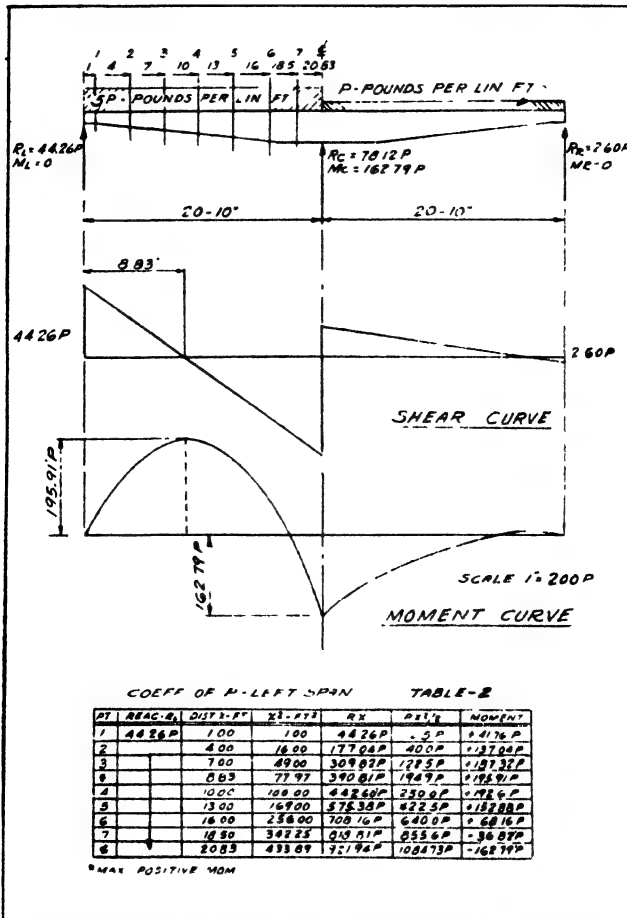



Fig. 7. Coefficients for moments in foot pounds half loaded, supported at 3 points.

On the conjugate beam the ordinates have been reduced to inch pounds divided by inertia, as coefficients of P. As will be noted, the curve formed by plotting these ordinates is irregular, and due to the negative moments a part of the curve falls below the beam axis.

The nature of the supports under the conjugate beam differ from those assumed for the original beam. Also, note only one half of the table, left span, is being used. The left side of the given or original beam, when considered independently, has a simple support at the left end and a fixed end beam connection with bending moment at the right end. The tangent to the elastic curve at the right end would ordinarily have a slope of zero, if it were a true fixed ended beam. The deflections of the spans on each side of the center support vary, consequently the slope is not zero; had this been true the right reaction for the conjugate beam would have been zero, in lieu of 21.65P. However, the deflection must be zero as we assumed the reactions all on the same level.

Solving the conjugate beam with its M/1 loading as we would an ordinary simple beam, the reactions are determined as shown by Table 5, Fig. 8. Knowing the reactions, the shear diagram could be constructed; however, aside

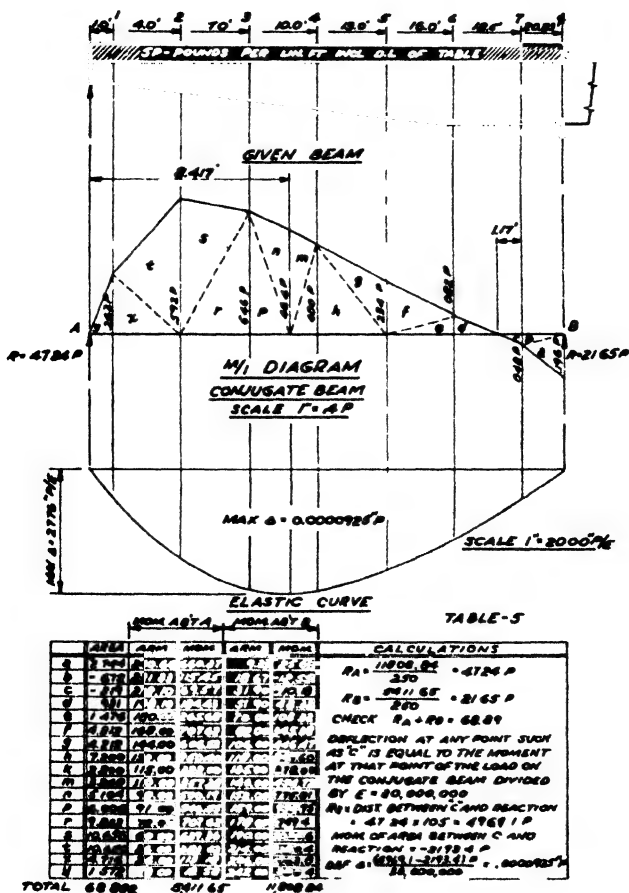



Fig. 8. Information used to compute deflection.

from the ordinates being a measure of the slope of the elastic curve, no special knowledge is gained by so doing. Also, it is difficult, with the type of loading, to accurately plot the shear diagram as each increment between the various points would be a parabola. (The loads are uniformly varying, represented by the horizontal axis and a sloping line. By integration the area between any two ordinates, the horizontal axis and the straight line, a parabola or equation of the second degree is formed.) Therefore, the slope or shear diagram has been omitted as being more theoretical than practical.

The ordinates for the elastic curve were determined by taking moments at the various points along the conjugate beam. Table 5, Fig. 8, furnished information by which these ordinates may be determined as was done for point C on the beam, shown on Fig. 8.

The maximum deflection is of serious importance in the design of the tilting table. The point of zero shear, or the point along the conjugate beam where the area between A and some point C are equal to the reaction, is the point of maximum deflection. This is evident from our knowledge of the relationship between shear and moment curves for ordinary beams; only in this instance we are dealing with slopes and deflections.

The area between A and C on the M/I diagram is equal to 48.53P, while the reaction at Ra equals 47.24P, therefore the point of maximum deflection is slightly to the left of point C. The deflection at point C has been accepted as satisfactory for the maximum value; and is stated 2776″P divided by E. By substituting 30,000,000 for the value of E, the

Maximum Deflection = .0000925-inch P.

In the conventional design of a steel structure, deflections not in excess of $\frac{1}{360}$ of the span (length in inches) would be assumed satisfactory. In the design of this fixture however, it was necessary to limit the deflection to the minimum amount that would allow the precision tolerances of the planer to be met. Here was a case where design from the machine-tool angle had to coordinate with structural; and as a result of meeting the low deflection requirements which controlled the sizes of the component members of the tilting table, relatively low fibre stress resulted, as follows:

The Span = 250 feet.

$$\frac{250}{360} = .6944 \text{ inch deflection.}$$

Assuming P = 2500 pounds

Deflection = .2313 inch for the table.

For the maximum fibre stress, $f = \frac{M}{S.M.}$

Moment, M = 195.91 foot P

S. M. = 340

$$f = \frac{195.91 \times 2500 \times 12}{340} = 1{,}729 \text{ pounds per square inch.}$$

The above value of 1,729 pounds per square inch does not take into consideration any forces that may be set up by the cutting tool, operating either longitudinally or transversely.

It will also be noted that on the beam on Fig. 7, a loading of 5P was used on the left span and P on the right span. The difference is assumed to be the weight of plate to be machined.

Fig. 10 shows the cutting forces also the resultant reactions. The plate to be machined is securely fastened to the table top, so that the cutting

SECTION-7 TABLE-[illegible]

SECTION	AREA IN²	ARM IN	MO[illegible]	[illegible]	[illegible]	[illegible]	I-IN⁴
A	40 00	1 25	50 00	8 19	67 00	2680 00	20.85
B	5 38	5 19	27 95	4 25	18 08	97 35	13 00
C	1 50	8.06	12 09	1 38	1.91	2 86	02
D	1 50	23 44	35 10	14 00	196 00	294 00	02
E	5 38	26 31	141 50	16 87	284.50	1530 00	13 00
F	12 00	29 50	354 00	20 06	402 00	4823 00	1 00
TOTAL	65 76		620 64			9427 21	47 89

C of G = $\frac{620\ 64}{65\ 76}$ = 9 44"

Ad² = 9427 21
I = 47 89
9475 10

SEC MOD = $\frac{9475\ 10}{20\ 56}$ = 461.5

SECTION-6 & ℄ TABLE TABLE-4

SECTION	AREA IN²	ARM IN	MOM IN³	d-IN	d²-INS	Ad² IN⁴	I-IN⁴
A	40 00	1 25	50 00	9 22	85.00	3394 00	20 85
B	26 50	15 75	417 20	5 28	27 90	739 00	1550 00
C	12 00	29 50	354 00	19 03	362.50	4350.00	1 00
TOTAL	78 50		821 20			8483 00	1571 85

C of G = $\frac{821\ 20}{78\ 50}$ = 10 47

Ad² = 8483 00
I = 1571 85
10054 85

SEC MOD = $\frac{10054\ 85}{19\ 53}$ = 515

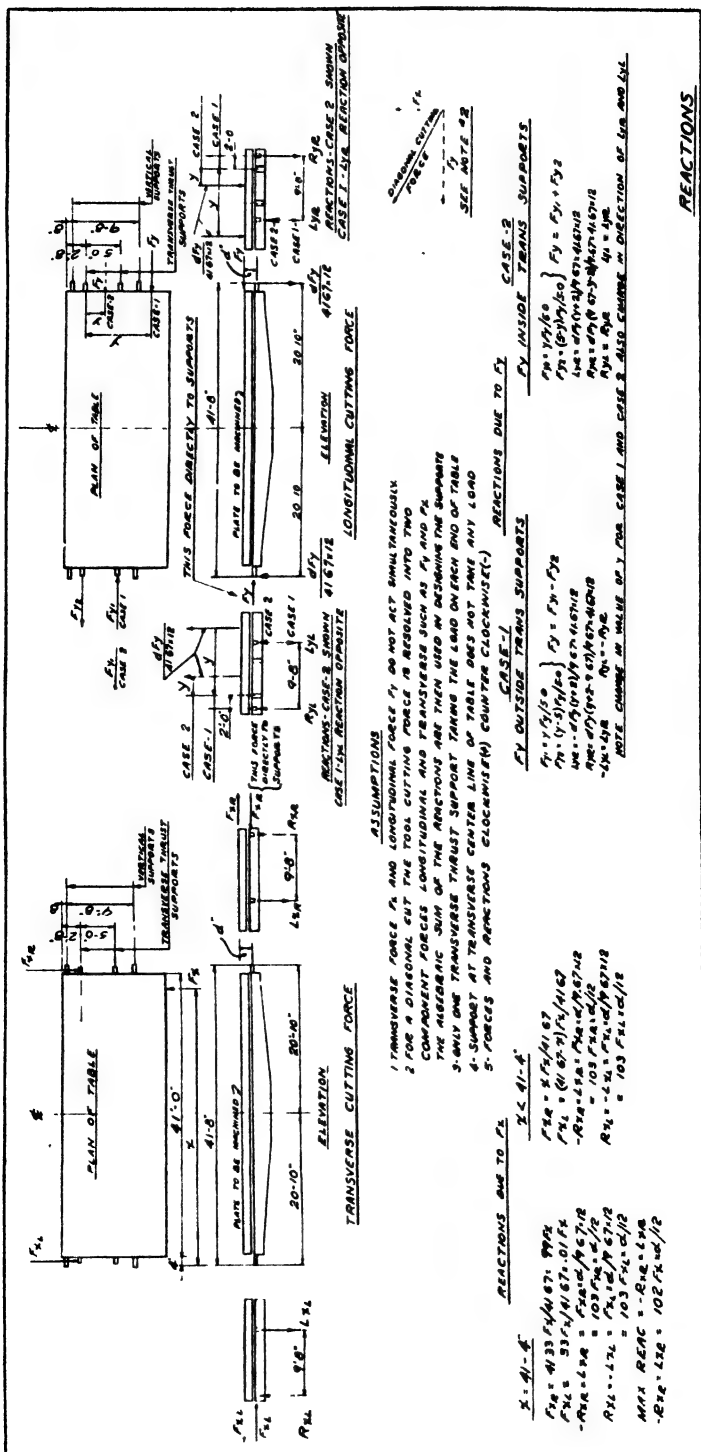
Fig. 9. Typical calculation for inertia.

forces are transmitted from the plate to the table top. This top is made up of a series of longitudinal and transverse heavy plates, designed to act as struts and beams. The forces in the table top are carried to the transverse thrust and vertical supports, also capable of handling the longitudinal thrust. Since these supports are definitely locked before any machining operations are performed, the table is rigid; and with the plate properly secured, accuracy in the machining is assured.

Fig. 11 shows the calculations for a section of the table acting as a strut also subjected to bending. The entire table top resists the bending forces; however only a small portion has been considered to take the entire load; this is on the side of safety.

The portion considered as a strut has a cross-section of 16-inches wide by 2½-inches deep, and 60-inches long. This section is also stiffened by the girder web. The calculations show that this section is capable of carrying 406,080 pounds while the assumed force due to the cutting tool is 22,500 pounds.

The portion subjected to bending is part of a continuous beam, supported every 5-feet. For analysis, a beam having fixed ends, with a span of 60-

Fig. 10. Reactions.

inches and a concentrated load at the middle is assumed, with an allowable fibre stress of 15,000 pounds per square inch. Under these conditions the allowable load as shown on Fig. 10 would be 33,333 pounds while the assumed force due to the cutting tool is 22,500 pounds. This does not take into consideration the reduction in stress as a result of other top members resisting the force.

If the 22,500 pounds are taken as the load for the struts, the compressive stress pounds per square inch would be 22,500/40 = 562 pounds per square inch. This added to the 1,729 pounds per square inch for the stress in the girder due to the dead load of the table and the plate to be machined, would equal 2,291 pounds per square inch.

In the case when two cutting tools are simultaneously operating in the longitudinal direction, there is also ample safety factor in the table to accommodate the force.

If the 22,500 pounds are taken as the load on the beam for bending, the fibre stress would be 10,130 pounds per square inch. This fibre stress when

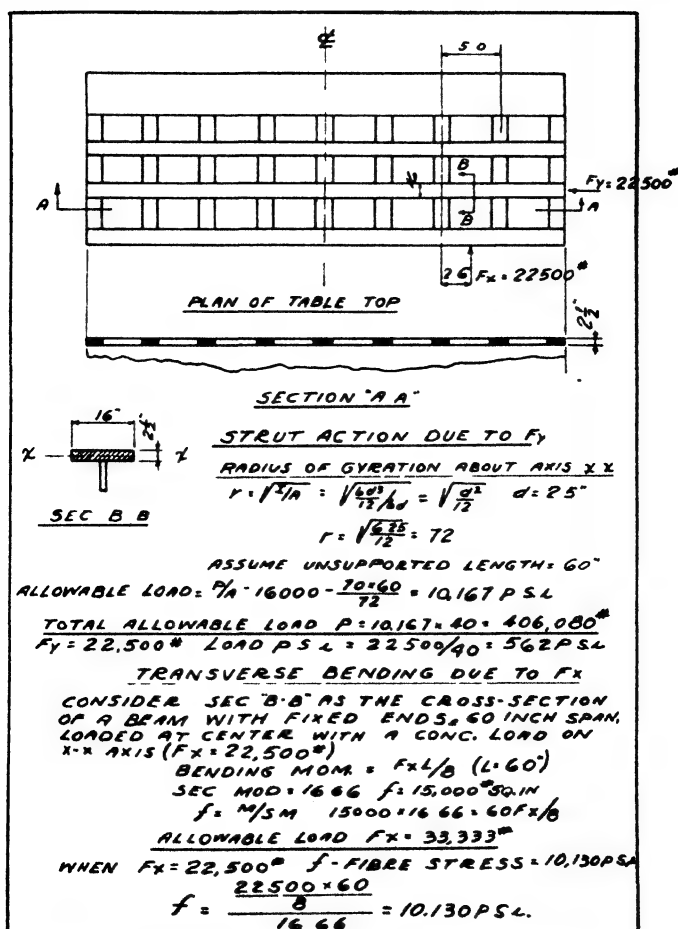



Fig. 11. Calculations for a section acting as a structure.

added to the 1,729 pounds per square inch fibre stress found for the dead load of the table and the weight of the plate is equal to 11,859 pounds per square inch.

The above figures indicate a wide margin of safety, but due to the important role minimum deflection plays in attaining precision machine work, it was not advisable to reduce the amount of steel in the table; furthermore, in a fixture such as this, holes may be drilled in the table top to accommodate a special piece of work, which could seriously weaken the table if there were no liberal margin of safety.

The stresses in the table are transmitted to resisting supports and abutments by means of sliding and link motion structural members of ample strength; these are necessarily deleted from the drawing. When the table is locked at the desired angular position, for any combination of longitudinal, transverse, and vertical thrust that might result from the enormous loads and pressures as the planer tools cut their way through the hardened and tough armor plate, the ends of the table are restrained in every direction.

This locking method insures rigidity which prevents vibration and chatter, and results in a fine quality of machine work; contributing also to this performance are the continuous welds used throughout the construction of the table, so that the large number of separate plates which form the table act as an integrated unit. All welds have been designed sufficient in size to transmit the stresses between the members joined.

One important feature in the use of the table is that there is no need to center a plate on the top surface. Close tolerances in the machine work are obtainable regardless of the location where the plate is fastened. Also, with ample total lifting capacity by means of air-operated jacks, a gigantic armor plate fastened to one end of the table can be raised without difficulty.

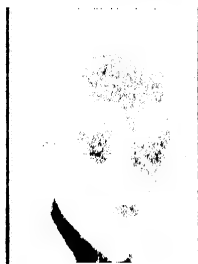
The tilting table is a 100 per cent arc welded job; it consists of 332 pieces of medium steel plate welded together into a rigid, homogeneous unit weighing 82,534 pounds; with the largest single piece weighing 7,167 pounds. The thicknesses of the plates that enter into its construction vary from 1- to 4-inches. The total amount of weld metal used in its fabrication and included in the above weight is 2,113 pounds.

After all welding was completed the table was stress relieved. This was performed not only to eliminate the stresses set up in welding, but also to relieve any strains set up at the steel mill during the rolling of the plates. This procedure assured a table whose all steel members would be free of internal strains. In effecting this process a convention type furnace, 53-feet long, 48-feet wide and 30-feet high, was employed. Sixteen thermocouples were attached to representative thick and thin sections of the table, and high and low spots in the furnace. These thermocouples were connected to 2 indicating controlling pyrometers so that the predetermined program, of temperature increase to 1150 degrees F. and decrease, was maintained. During this heating cycle, twenty-seven hours of uniformly rising temperature was expended in reaching the above limit. This degree of heat was held for nine hours. Controlled cooling then followed for a period of three hours, after which the table was allowed to cool off naturally in the furnace.

The authors do not wish to close this paper without paying tribute to the splendid workmanship performed by members of the welding, structural, forge, and machine shops of the Philadelphia Navy Yard who were privileged to play a part in the construction of the tilting tables, instrumental for the most efficient production of the giant armor plates destined to protect our fighting men and ships.

Chapter XVIII—Base of Tilting Fluoroscope

By Walter H. Haupt,

Mechanical Engineer, Kelley Koett Manufacturing Co., Covington, Ky.

Walter H. Haupt

Subject Matter: When welded steel was first used for this base, it was designed for strength and was sufficiently strong, but was not rigid enough. Rigidity is essential in order to hold the subject and the fluoroscope, as well as photograph plate absolutely fixed in position if clear pictures are to be secured. Investigation showed that there was not sufficient torsional rigidity. The paper shows how this was secured, e.g., a channel can have its rigidity increased many times by welding thin strips across the tips of the flanges. By securing improved torsional rigidity the design was satisfactory and great savings were effected in weight, in cost, but most of all in time. The United States army is giving rush orders which could not be met if it were necessary to secure castings, patterns, machine work, etc. Welding avoids all this. Cost saving is shown to be 58%.

The simple unit structure which forms the particular subject of this paper is certainly not a spectacular innovation in the art of arc welding. It does, however, represent a radical departure from the traditions of our industry, and certain conditions had to be met that in the opinion of the author have not been given sufficient emphasis in arc welding literature. We feel that these conditions may exist in so many cases that the solutions we have worked out and applied to the present structure will probably have very broad application.

In preparing this report we have, therefore, particularly stressed these problems and their solution, rather than confine ourselves to the description of the machine base with which this article is concerned. Particular emphasis in this case will fall upon the comparison of the new design with the one of cast iron that has been replaced.

We are building X-ray machines. In most applications a relatively heavy unit containing the X-ray tube must be easily manipulated into position opposite the film. The object to be X-rayed is supported on a ray-transparent surface between the film and the tube. The photographs or radiographs made

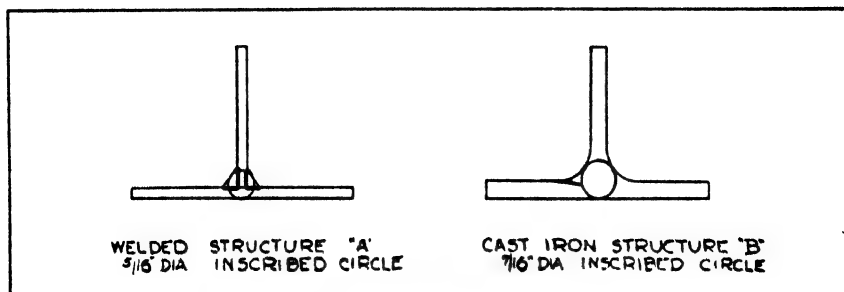



Fig. 1. Welded steel and cast iron compared.

are the pictures of shadows cast on the film by the varying density of the interposed object. The supporting surface and film are usually movable, but the tube itself is supported in such a manner that it is adjustable over a considerable range in all directions and can be rotated about at least two axes. The source of the rays is made as small as possible, consistent with the power output. To obtain sharp shadows it is, therefore, necessary that the supporting arms, substructures, etc., eliminate any relative motion. Movements, such as swaying or vibration after the parts have been positioned will cause the pictures to be blurred, defeating the efforts of the tube manufacturers to keep the effective source of rays small. Traditionally X-ray apparatus is light in weight for installation in hospitals and offices. It is rarely in continuous operation hence there would be no justification, or sale for apparatus built with the

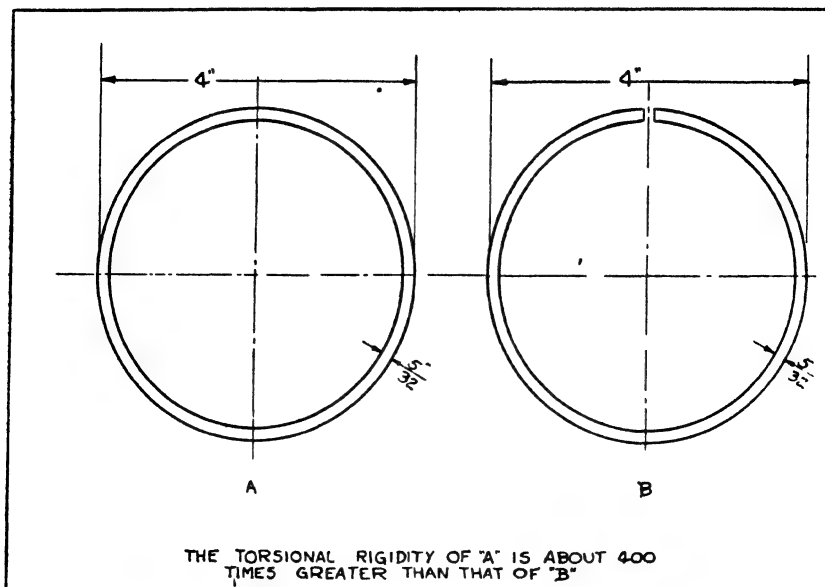



Fig. 2. Solid and split tubing compared for torsional rigidity.

ample weight and proportions of a radial drill, together with its motorized controls and movements. In most cases X-ray apparatus is built with large numbers of ball bearings and the moving parts are carefully balanced by weights so that a minimum of effort is required to position parts of the apparatus.

As a rule the supporting structures have been made of cast iron, with intermediate members and tracks of cold rolled steel or steel tubing. A generous proportion of aluminum was used in the moving parts, and lead was required for balance weights, a combination which in the present emergency literally begs for substitution.

Our first attempts to replace cast iron supporting structures with arc welded steel were made about three years ago and were considered very successful both from the points of view of performance and cost. These bases, however, were never adapted to our regular line, and the author had the feeling that the results obtained were gained by the use of generous amounts of material and liberal proportions rather than by the most economical and sound

application of the possibilities implied in the use of the newer type of construction.

We, therefore, approached the problem from the engineering angle, calculating loads and stresses in two directions and building to meet the rigidity requirements. However, in nearly every structure we found that there were set-up, as a result of manipulation or adjustments, temporary vibrations which continued after the structure should have been completely at rest. Although we had provided amply for vertical and lateral rigidity the structures did not compare favorably with those we were attempting to replace. At this point, we were met by old timers' fallacious arguments that cast iron was stiffer than steel and we had to resort to a series of actual demonstrations on comparable samples to allay objections. However, more careful observations showed us that the incidental temporary stresses and vibrations were torsional and further study comparing the old and new structures revealed the reasons for lack of torsional rigidity.

To illustrate this point, Fig. 1 shows a logical substitution of a section of steel made by arc welding, contrasted with a similar section of cast iron. The steel section "A" has greater strength and rigidity for bending stresses than the cast iron section "B". The torsional rigidity of either one is primarily a factor of the fourth power of the diameter of the circle that can be inscribed in the fillet. Comparing these two by a simple calculation (#1) we find that the cast section is nearly four times as stiff under torsion as the steel section of the proportions shown. It may be pointed out that the fillet in the steel structure could readily be enlarged, but unless this point is borne in mind it is likely that the steel structure was formed either by intermittent or staggered welds, and then we do not have even the continuous $\frac{5}{16}$-inch diameter section upon which the calculation was based.

(#1) $$\frac{\text{Rigidity "B"}}{\text{Rigidity "A"}} = \frac{(7/16)^4 \times (\text{Torsional Modulus of Elasticity for C.I.})}{(5/16)^4 \times (\text{Torsional Modulus of Elasticity for steel})}$$

$$= \frac{(7/16)^4 \times 5{,}600{,}000}{(5/16)^4 \times 12{,}000{,}000} = \frac{3.8}{1}$$

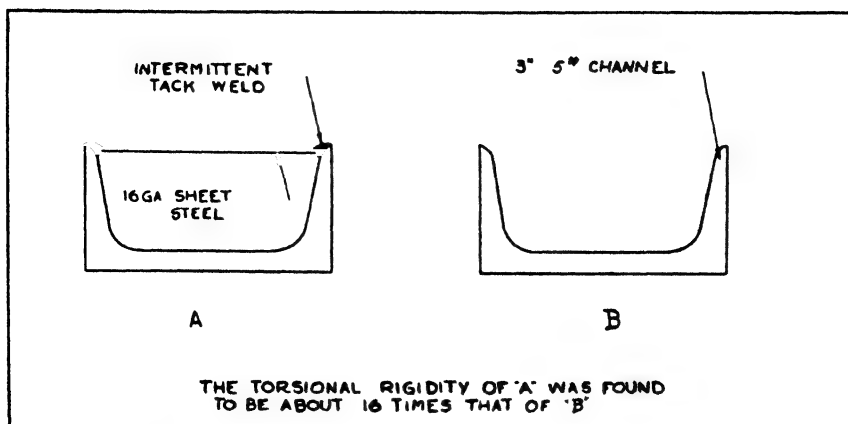



Fig. 3. Open and closed channel compared as to torsional rigidity.

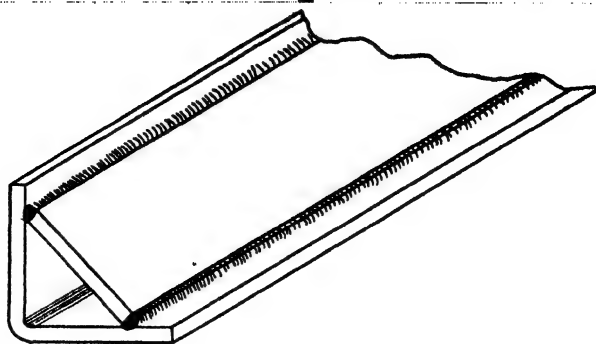



Fig. 4. Obtaining torsional rigidity by bridging in corners.

Another factor that entered into the problem which was not taken into account until later was the vibration damping effect inherent in cast iron. This caused vibrations which were set up in the cast structures to die out more quickly than they did in steel.

And so we found that in order to obtain characteristics comparable for the purpose with the older designs we had to greatly increase the torsional rigidity and thereby eliminate the vibrations that required damping.

We made several designs incorporating pieces of tubing as torsion members into our structure at critical points but found this expensive and often awkward to do.

We were encouraged by calculations shown in Raymond J. Roark's "Formulas for Stress and Strain". One particular comparison (#1) illustrated in Fig. 2 showed that a piece of tubing $\frac{5}{32}$-inch wall and 4-inch outside diameter has approximately four hundred times the torsional rigidity of the same tube split lengthwise. We realized that it would not be difficult to appreciably increase torsional strength by closing certain structural elements with bridging of thin sheet metal. An example of one of our tests on a three inch channel is illustrated in Fig. 3. The open channel was submitted to a twisting load and the deflection measured. A similar piece of the same channel (3 A) was closed by tack welding a piece of 16-gauge sheet steel across the top of the flanges. The deflection for the same load was reduced to about one sixteenth of what it was for the open channel.

In our further designs our tendency has been to use much thinner gauges of steel than at first, and to provide torsional strength by bridging corners, (See Fig. 4). Sometimes it has been found desirable to provide double thickness in adjacent sections for bolting and attaching other parts of the machine. In such cases we have provided torsion members attached wholly or partly by plug welds as in Fig. 5, because these plug welds could be placed near the corners of the triangular section where they belonged to make the bracing effective, (See also Fig. 6).

Thus having determined certain essential elements of the desirable supports we have been able to design without further experimenting suitable

(#1) Roark's "Formulas for Stress and Strain," 2nd Edition, Page 160.

structures for arc welding, and have found these structures far lighter, and more economical as well as much more rigid than any previous designs.

The particular base of a tilting fluoroscope which we shall proceed to describe represents the application of the above studies and experiments to a special machine designed to meet certain specifications proposed by the medical division of the United States army.

The time allotted for completing the machine and submitting cost estimates was less than the time that would ordinarily be required to make new metal patterns and make sample castings from them. The proposals made by the army differed from our standard machines primarily in the omission of certain features usually demanded by the medical profession. However, when we calculated the cost of our standard job, omitting these items we found the cost was still far above the price range suggested by the army men. Furthermore the production of these tables in the quantities indicated, would have handicapped us in the milling machine department which is practically the bottle neck of our present production.

A new design, made entirely of steel by arc welding, and taking full advantage of the simplification possible due to omitted features was completed under pressure. No special equipment or tools were needed to complete the sample table and no time was lost obtaining the material, mostly 10-gauge sheet steel. Even so, before we had time to rust-proof or paint the various parts we were requested to submit the table in the raw to inspection and tests by shipping it to Washington.

By no other method could we have completed the sample in so short a time; by no other method could the raw product have presented such a neat and finished appearance as did the arc welded job submitted. The unit proved to be far more rigid than any previous structure in its class, and was much lighter in weight. Both of these advantages were considered of major importance.

Let us now proceed to analyze the construction of the base as it was built to meet its functional requirements. The base consists of a front and rear leg

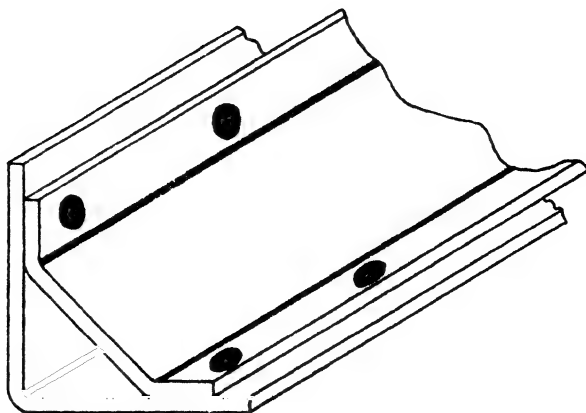



Fig. 5. Torsion members attached by plug welds.

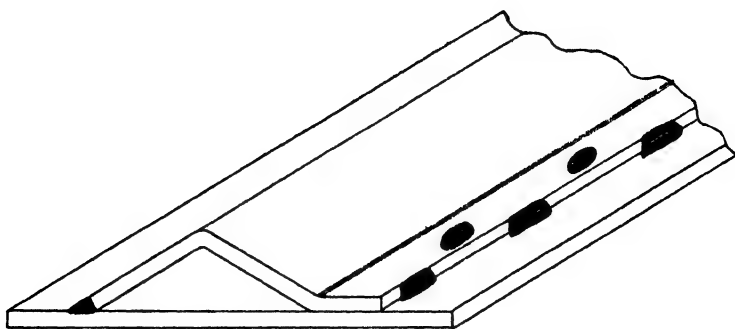



Fig. 6. Torsion stiffening applied to flat plate.

designed to carry an X-ray unit, transformer, table top, 250 pound patient, and a fluoroscopic assembly, all pivoting on a pair of bearings located near the top of the base. The front leg is very shallow. It is raised from the floor by a pair of blocks and leveling screws so as to provide toe clearance. Thus the operator can stand very close to the unit. This leg serves merely as a vertical support but is weak against lateral loads. The rear leg also on levelling blocks is built like an abuttment, and takes any lateral loads that may be applied, the load being transmitted from the front to the rear by the intermediate parts. A closed triangular element shown in section "A" in Fig. 7, placed where it will not interfere with other parts of the complete assembly, ties the front and rear legs together acting as a very stout torsional member. This member will cause the unit to rock on three levelling feet if the fourth is not adjusted, rather than permit the bearings to move out of line with each other. In addition to this main torsion member each bearing block is tied to the main torsion member by a closed triangular section welded to the left flanges of the front and rear legs. These prevent the bearings from twisting if the pivot studs on the supported structure should tend to do so. The flanges on both legs are turned in and the outer surface is a large smooth triangular area of extremely neat and simple appearance.

In building up this base we first machine the two bearing blocks on a lathe. Bushings are pressed in and reamed in alignment in the final assembly. These bearing blocks are placed on a spacer bar in their correct relative position and the remaining parts of the base are positioned and welded in relation to these blocks.

Milling operations were entirely eliminated. Other machining except for the bearings mentioned was limited to drill press operations. Finishing time and costs were cut greatly because of the elimination of plastering, etc., before priming, which had been necessary on the cast iron bases.

Costs on the first model were not used as a basis for production costs, but our estimates were compared with those made by commercial welderies that could be called upon to assist us in producing these bases. The figures arrived at were astonishing when compared with the known cost of our previous

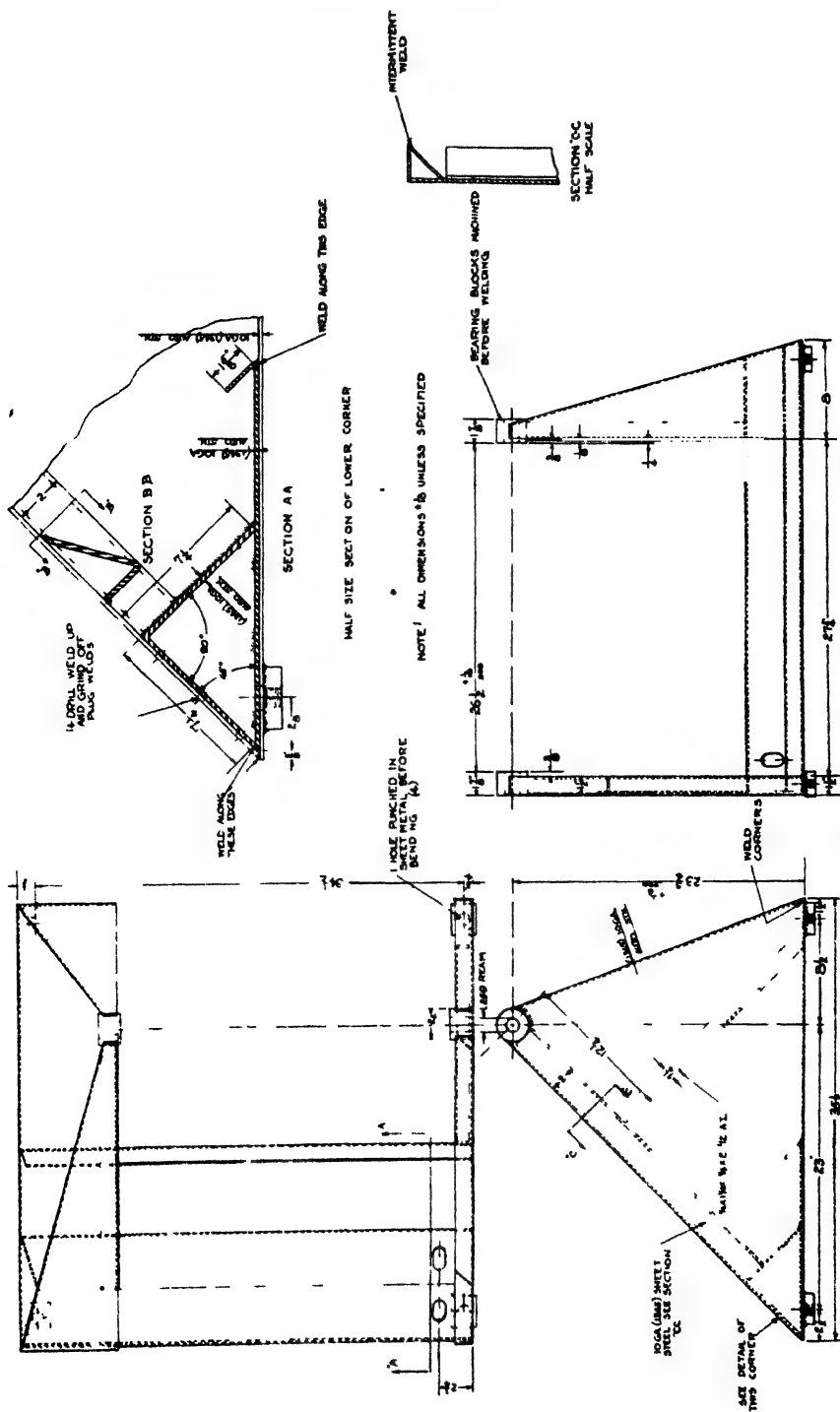



Fig. 7. Base of tilting fluoroscope designed for arc welding.

assemblies. The reduced cost and the incidental advantages of reduced weight and increased strength have brought us to the conclusion that we will have to redesign our entire line for the far more extensive use of arc welding at the earliest possible moment.

A comparison of the arc welded and the previous cast iron base from manufacturing figures will be of interest.

Cast Iron	Material Cost	Machining Cost	Finishing	Total
Front leg	$7.16	$4.34	$7.50	$19.00
Rear leg	7.51	6.24	7.25	21.00
Connecting members	2.00	1.40	.60	4.00
Total cost of cast assembly				$44.00
Arc Welded Base				
Material cost			$ 6.00	
Labor and welding			6.00	
Machining			2.25	
Finishing			4.50	
			$18.75	
Saving per unit in cash			$25.25	
Saving in percent of original cost			57%	
Saving on an estimated year's production of 400 tables				$10,100.00
Weight of Cast Iron front leg			97 lbs.	
Weight of Cast Iron rear leg			102 lbs.	
Weight of steel connecting members			46 lbs.	
Total weight			245 lbs.	
Weight of arc welded base complete			115 lbs.	
Saving of weight per unit			130 lbs.	
Percentage of weight saved			53%	

Material saved on a year's production of 400 tables is 52,000 lbs. or 26 tons of metal.

The advantages of reducing machining time in production, particularly eliminating milling operations cannot be overestimated in our present situation. The possibility of producing the sample in the time allotted, was a definite necessity in this case. We would have suffered a serious setback without the use of arc welding. The reduction of shipping weight of machines that may be sent wherever the army goes is a real asset. The elimination of the hazard of breakage through rough treatment in transportation is a big factor favoring the new design. The smooth flat surfaces are not only an advantage in the finishing of the base, but an important sanitary factor on a hospital unit, making it easy to keep clean and sanitary. The extreme rigidity of the base will assist in yielding quicker and more accurate diagnoses of casualties than a shaky structure and may contribute strength to the thin thread by which some life is hanging. This same rigidity will reduce wear and tear on bearings and other parts due to misalignment, and a long service life will result. Should damage result to the base through accident it is reasonable to assume that repairs can be made quickly and locally by any one skilled in welding.

The advantages which we have worked out in this particular arc welded base we attribute partly to the increased knowledge of the possibilities of arc welding which we gained by the various simple studies and experiments which were described in the early part of this report. We feel confident that we can apply this background of experiment and experience to good advantage in an

endless number of related structures. With torsional stiffeners well placed it is surprising what can be done with very thin sections of sheet steel. Our problems are not unique and we hope our presentation will help others to save money and precious material and to gain strength and rigidity for future designs, particularly where lightness and strength must be combined.

It is very difficult to make an estimate of the saving which a design like ours could produce in industry as a whole. The total number of units, of the type for which this base was built, produced in the United States in one year, is about two thousand. Therefore the annual saving for this industry as a whole would be about five times what we have estimated for our company, that is, $50,500 in cash and about 130 tons of metal.

We would rather take into account the savings that could be produced by the increased knowledge and understanding of the effects of torsional stresses and how to meet them in arc welded structures, as we have tried to emphasize. The savings that could then be made by application of these elements to allied designs would really be unbelievable.

Chapter XIX—Arc Welded Motor Drives for Machine Tools

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Subject Matter: The economic advantage of converting older machines now equipped with belt drives, to motor drives. The savings effected are shown in detail—more work turned out faster and more variable speeds available, safer, too. The writer then devotes the remainder of paper to a comparison of cast iron and welded steel brackets, columns, etc., for the motors. He shows that the arc welded designs are cheaper, stronger, of better appearance, etc.

Part One—Analysis of the Need for Motor Drives and of the Benefits Directly Traceable to Their Use—For a number of years it had been the trend in modern industrial development to consider a machine tool as an individual and self-contained unit. This unit, however, is treated as an integral part of a carefully studied plant layout.

The results of the study of the spacial relationships of machine tools applied to production problems have been spectacular. Thousands of specific operations are now done in one-fourth to one-tenth of the time previously spent on the same job. A considerable share of the credit for this amazing jump in plant productivity can be given to the individual motor drive. Machine tool manufacturers realized the benefits of individual motorization years ago. They initiated motor driven models of their machines. These models became so popular that they now monopolize the field.

Machinery has been built in quantity, however, for 50 years or more. It is common today to see machines 30 years old in active service turning out a creditable run of work. These machines are still valuable, and it is poor economy to junk them for new equipment. On the other hand, as originally built to run from a line shaft or jack shaft, they are usually unable to compete on even terms with modern, motor driven equipment. The reasons for this are immediately apparent.

Placement of Machine Tools—Self-powered machines can be placed to their best advantage in any given production line. Their position is not dictated by the presence or absence of a line shaft. If changes in tooling are made, machines easily can be moved to a new location in a very short time.

This mobility of machinery is of inestimable value. It allows the proper sequence of manufacturing operations. Economy of tooling is thereby effected, and waste motion, both of men and job parts, is considerably reduced.

Speed—It is usually true that line shafting set-ups have not been changed for a number of years. Changes in speed ratios are difficult and costly to make, and this contributes to the fact that a great many machine tools now

operating from line shafts run at improper speeds. Usually the speed is too low. When the shafting was first erected, pulley ratios were probably figured correctly for the spindle speeds then used. However, tools and lubricants have improved so much in recent years that cutting speeds and feeds on numerous operations average 50 per cent higher than they were fifteen years ago. If line shafts have not been speeded up proportionately, the machines are crippled. The writer has found this to be the case in a number of specific instances.

Another factor contributing to incorrect spindle speeds is the difficulty in changing belts from one cone step to another. The usual method of changing speeds is by shoving the belt over with a long pole. This is a difficult and dangerous procedure. It takes valuable minutes of a man's time. Since it is not easy to do, the operator's tendency is to leave the speed where it is. Work suffers as a consequence.

Power—In order to be effective, a machine tool must have a positive and steady pull. There is no take-up in line shafts, and the result of stretching belts is slippage. This means wasted power and a consequent increase in overhead, as well as inferiority in the work produced.

Maintenance and Overhead—Line shafting is expensive to keep in good condition. Heavy, wide leather belting costs a great deal of money. Bearings and bushings must be kept lubricated. Belts must be shortened when they stretch. Most large factories employ at least one man to take care of belting alone.

A more costly consideration is that which pertains to down time. When a line shaft fails, a whole battery of machinery becomes idle. A double expense is thereby incurred. The machinery is not working, and the idle men must still be paid. One large plant,* which subsequently motorized their equipment, estimated that 10 per cent of its machinery was down at all times. Nearly one-fifth of this total was due to line shaft failure.

Improvement in Working Conditions—Studies have been made by very large concerns to determine the relationship between worker psychology and production. The results obtained have led to many refinements in working conditions. Shops are cleaner, cooler and lighter. Men are given rest periods. Canteens have been set up. Toilet facilities have been improved. Production figures, as a result of these changes, have gone steadily higher. A specific example illustrates this point. One small plant, motorized by this company, found that production jumped 20 per cent as the combined result of motorization, and more conveniently located equipment in a new building. Most of this increase was due to the convenient and pleasant working conditions established through the use of individual motor drives.

Motorization unquestionably is a primary factor in the improvement of working conditions. Compare Fig. 1 with Fig. 2. Fig. 1 shows a battery of Gridley automatics in a ball bearing plant. The maze of belts is nearly unbelievable. Inspection will show the first of the motor drives which eventually replaced all the belting in the picture. This plant is now considerably more spacious in appearance, and production rates are higher than they were.

Fig. 2 shows the end product of motorization. This shop is an excellent example of how motor drives can improve a plant's appearance.

Certain conclusions can be drawn from the above discussion. Drive manufacturers usually estimate that the motorization of old machine tools results in a 25 per cent increase in their productivity. The writer has been told on

*In this paper names of plants cited as examples will not be given. Their identity can be established by communication with the author.

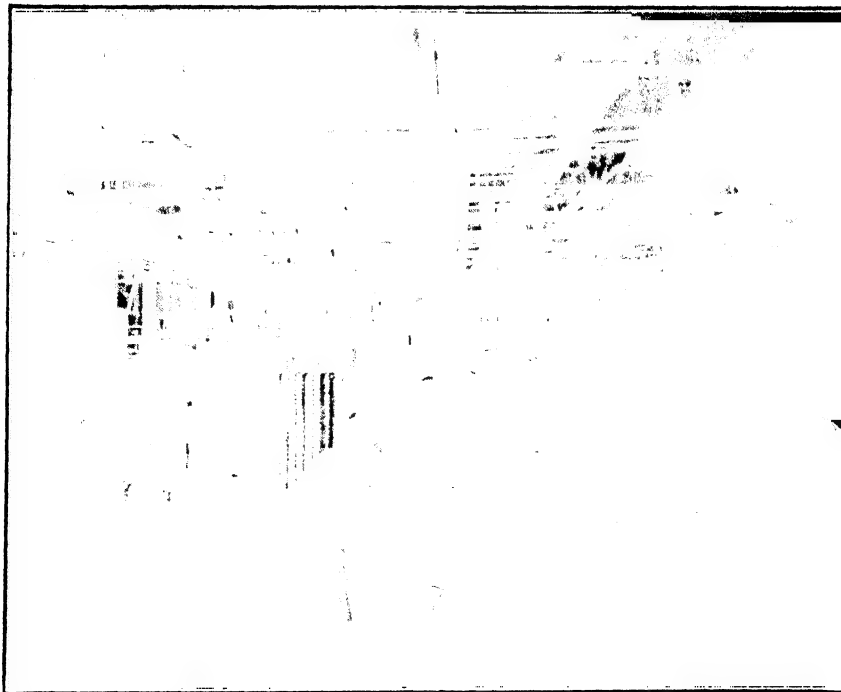



Fig. 1. Bad belting conditions due to placing automatic machines too close together.

several occasions that motor drives have paid for themselves in a year or less. In our own plant, which was motorized from the beginning, we have no figures upon which to base a comparison.

Assuming that a production increase, or cost reduction of only twenty per cent is realized through motorization, the savings are still tremendous. The writer has no sure way of telling how many machines have been motorized in the last two years, but a fairly true estimate can be made.

There are six large drive manufacturers and a number of small ones. Conservatively estimating their output with respect to our own, by comparison of the number of competitive drives seen in various plants, it is safe to say that 25,000 machines have been motorized since January 1940.

Assuming the average earning capacity of each of these machines to be $2.50 an hour, certainly not a high figure, the sum of the earnings made by these 25,000 machines is $130,000,000 per year. This figure is based on fifty-two forty hour weeks.

If 20 per cent of this total profit is due to motorization, $26,000,000 per year has been made through the use of motor drives. This share of the value of work produced must be balanced against the cost of the drives. If this is an average $100 per unit, the drives cost $2,500,000. Added to this is another $2,500,000 for motors and electrical equipment.

The increase in productivity derived from motorization is seen to be $26,000,000 per year, or a total of roughly $62,800,000 from January 1940 to June 1942. Subtracted from this total is the $5,000,000 spent for motor drives. On the other hand, this $5,000,000 can also be turned into profit. Ninety-nine out of a hundred machines motorized have theoretically depre-

ciated to minimum value before the motorization. Upon their renovation, they became capital assets of a quite considerable value. It can be stated as fact that the value of most machines motorized is increased from one to ten times.

Fifteen per cent of the total advance in earnings of $62,800,000 since January 1, 1940, or a sum of $9,420,000, can be conservatively credited to arc welded motor drives. As will be brought out later in this paper, if all the drives built were welded, probabilities are that earnings would have been about 5 per cent more than those given in the above hypothetical example.

It must be emphasized that these figures are purposely low. The total number of motorized machines is much higher than the number used in the example. Most machines now run 18 to 24 hours a day instead of eight, and they make more than $2.50 an hour for their owners.

The benefits resulting from the motorization of machine tools have been enumerated above. The next section of this paper will deal with the role of arc welding in their manufacture as opposed to cast construction.

Part Two—Comparison of Arc Welded Drive Units with Cast Iron Types—The comparison of arc welded construction of motor drives with cast iron construction, the only feasible alternative method of manufacture, brings out a number of important points in favor of arc welding.

This company originally built motor drives of cast iron. In 1936 an experimental welded steel drive was built and tested on one of our own machines. This drive still runs the same turret lathe.

The surprising results of this experiment can be tabulated briefly as follows:

1. Material and labor cost of the test column was $12.85. The cast iron drive it replaced cost $15.07. This was a cost reduction of 15 per cent.
2. A 10 per cent saving in the erection cost was noted. The reason for this was the light weight of the all steel drive column, which materially aided the millwright.
3. The steel column absorbed shock more efficiently than did the cast column. The quality of work done on this one machine was improved because the power transmission shocks were dampened.
4. Most important of all, arc welded drives allowed the manufacture of any conceivable design for any possible application. Since 1936 this company has produced 3100 distinct drive types. Most of these are variations of standard units. At least half of these types were used only once or twice, since they were designed for special equipment which is rarely found in industry.

Since motor drives sell for as little as $26 and rarely cost more than $300, it is obvious that this company could not have afforded the huge pattern cost, were each of these drives made from cast iron.

Point four is of the utmost importance. Most drive manufacturers today are content to build a few sizes and styles of standardized brackets. Their belief is that most machines can be motorized with these standard shapes. At the same time they feel that money is saved as a result of quantity production.

Both of these points are partially true. The writer does not mean to cast aspersions upon competitive products, but it is necessary to analyze these two factors. Arc welding is distinctly superior to cast iron construction in drive manufacture, and the reasons must be stated.

Any engineer will agree that a machine part built for a specific purpose will do a better job than an item which serves many similar purposes. An adjustable wrench will fit many sizes of nuts, for example, but an end wrench will tighten one nut more times without springing.

It is the same with motor drives. When arc welded forms are used, a properly engineered drive can be built for any machine that has a wheel to turn. There is no necessity, for example, to carry a cast column eight inches behind the back gears of a small lathe, merely because patterns have to be made which fit all similar machine types.

There is no necessity for the purchaser of a drive to weld up a sub-bracket upon which to mount the standardized cast drive. An arc welded drive can be built to fit any mounting condition. There is no necessity to brace a

Fig. 2. Improved working conditions by motorized equipment.

shaky cast drive with straps and bars. If insufficient mounting space is available, the arc welded drive can be designed to utilize any possible additional points of support, such as shown in Fig. 3. There is no necessity to chip off sections of a cast column because the custom built welded drive can make allowances for obstructions. These points illustrate the fact that a properly engineered arc welded drive can be mounted in 10 to 25 per cent less time than a similar cast drive.

A drive designed to fit a certain machine is also better looking. Instead of appearing as though it were "stuck on", it becomes an integral part of the machine and performs as such. A glance at Fig. 4 will show this to a marked degree. In Part I it was stated that a welded steel drive produced better work on the same machine than did the original cast drive. This saving alone can add up to perhaps 5 per cent. It should be understood that there are numerous outstanding exceptions to this statement. Some cast drives, such as those sometimes built by the original equipment manufacturers, are very good.

The superior strength of steel columns compared to cast iron columns of the same dimensions can be seen from figures of their average strengths.

	Medium Cast Iron	Structural Steel
Tensile strength	22,000	60,000
Compression	100,000	60,000
Shear	24,000	45,000
Yield point		30,000
Modulus of elasticity	16,000,000	29,000,000

Drive columns are subjected to external stresses which include tension, compression, bending, shearing, and torsion. They are built strong enough to carry, as dead weight, hundreds or thousands of pounds in excess of their actual loading. The difficulty in their design is the necessity to cope with vibration set up by unbalanced rotating members.

One of the major faults with nearly every cast drive column manufactured today is that the width of the column exceeds the depth. Correct design dictates that the greatest depth of metal be in the direction of greatest stress, which in most drives is the belt load.

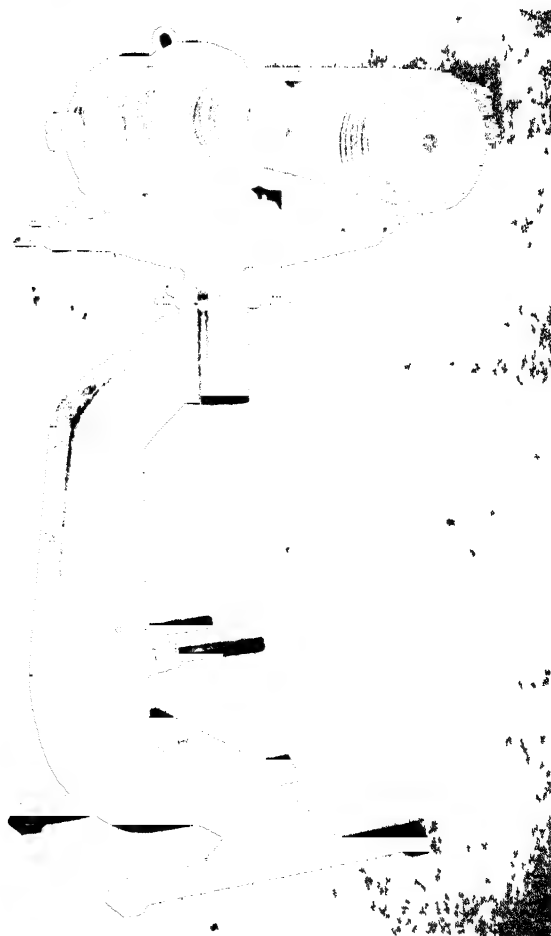



Fig. 3. Heavy-duty 15-horsepower drive of all welded steel construction.

Fig. 4. Low-swing lathe with welded steel pulley drive.

The resistance of a column to bending increases as the square of the column's depth in the direction of the force, and only directly as its width, according to the formula for the section modulus Therefore, most cast drives, which are wide but not deep, are incorrectly designed.

The box section affords the greatest resistance to stresses applied in two directions for any given weight of metal, but it is difficult and costly to cast. As a result, most cast columns are made in T-section or channel section. These shapes are structurally unable to resist the stresses set up in a drive Since they are of an unsound cross section, more metal must be used to make them capable of carrying a given load.

And since they are cast iron, roughly 30 per cent more metal has to be used than if they were steel, even if the cast column were in box section. For economy of materials, therefore, it is unwise to use cast iron for columns and brackets.

Calculations for strength of columns under different sets of stresses are quite complex, and will not be illustrated here. It is sufficient to say that any given cast iron column must be at least 30 per cent heavier than the equivalent steel column, if both are box section. If the cast column is channel or T-section, it must be 70 to 150 per cent heavier if designed to resist the same loadings. Drive manufacturers realize this, and in order to build cast columns

as light as possible, they depend upon external support to make up the deficiency of design and metal.

If, to the improper shapes used in cast iron columns, is added the fact that they are designed with deep throats and great length to fit many different machines, it can be realized that a cast iron bracket is most inferior to the equivalent steel column. Another important consideration is that cast columns often break, especially at the base, because of their brittle material.

In conclusion, it is possible to design a cast iron drive which is cheaper than the corresponding welded steel drive. It can be done, however, only at a sacrifice in efficiency, appearance, and durability.

To illustrate the impracticability of attempting to build a cast drive equal in performance to an arc welded drive, the recent experience of this company will be cited.

In June 1941 we decided to make a cast iron unit to fit average lathes and screw machines. The column was not to be inordinately deep and long in order to achieve versatility, and the features of the welded steel drive were to be duplicated as far as possible, (See Fig. 5).

A box section column was designed with careful attention to wall thicknesses. All the mating parts were carefully machined in welded jigs and fixtures, to fit together closely.

When the job was done we found the resultant drive to be inferior to our standard product, and that its cost, in an attempt to equal the performance of the welded steel drive, was greater by 34 per cent. The original order was for 25 units, and we took the drive from the market after selling thirteen.

Cost data of this cast drive compared to that of the standard unit follows. In all the cost analyses to follow, only labor and material costs are considered.

Fig. 5. Cast iron drive mounted on hand screw machine.

Our overhead includes welding wire, gas for flame-cutting, and engineering expenses. Cap screws, sheaves and belts and other finished materials are not included.

Cast Transmission Drive

Material				
Column	58#	@	$ .09	$ 5.22
Head Casting	32#	@	.08	2.56
Ram	19#	@	.06½	1.23
Motor Arms	10#	@	.07½	.75
Clamps	5#	@	.10	.50
Total				$10.26

Labor	
Column	$ 2.75
Head Casting	1.07
Ram	1.04
Motor Arms	.70
Clamp	.21
Assembly	.60
Total	$ 6.37
Total Cost, Material and Labor	$16.63

Standard Welded Steel Drive*

Material				
3/16" Plate	35#	@	$ 4.60 per cwt.	$ 1.61
¾" × 6" H.R.S.	11#	@	3.65 per cwt.	.40
2½" Pipe	8"	@	23.54 per 100'	.15
Seamless Steel Tubing	14"	@	63.92 per 100'	.76
2½" Round C.D.S.	20#	@	5.04 per cwt.	1.40
¼" Plate	8#	@	4.75 per cwt.	.38
½" × 8" Bar	7#	@	4.75 per cwt.	.33
Total				$ 5.03

Labor				
Cut	.5 Hr.	@	$1.00	$ .50
Weld	2.7 Hr.	@	.85	2.29
Grind	1.0 Hr.	@	.55	.55
Machine Work	1.4 Hr.	@	.70	.98
Ream	.8 Hr.	@	.60	.48
Assembly	.8 Hr.	@	.70	.56
Total				$ 5.36
Total Cost, Material and Labor				$10.39

*The set of figures given for the Standard Welded Steel Bracket are the same as those given in Part Four, as an example of our most recent cost analysis of the transmission type.

Pattern cost for the cast drive was $148.95. Jigs and fixtures were $124.38. In quantity production this total of $273.33 would be absorbed to the vanishing point. This drive, although the equal of any cast iron drive on the market, could not compete on even terms with the welded unit. Customers who bought both styles specified the welded steel drive on their repeat orders. Hence, it was discontinued, and the remaining columns lie in storage.

These comparative costs may seem out of line. The writer can give assurance that they were checked most carefully with the help of the office manager of this company.

The conclusions that can be drawn from the above discussion are most important. On our own machine, and subsequently on all our machines, the welded steel drive allowed the production of superior work. It is the belief of the writer that a 5 per cent increase in production can be established with the use of welded steel drives as opposed to the use of cast iron drives.

It can also be seen that welded construction is not able to compete on an event cost basis with cast construction, if in the latter no attempt is made to equal the performance of the welded steel drive.

If castings are so designed that they nearly equal performance of a similar arc welded unit, then the cost is exorbitant, if our own experience is any criterion.

Part Three—Description of the Fabrication of Arc Welded Motor Drives—The sequence of operations used by this company is simple. When an order for a drive unit is received, it is first sent to the engineering department. The sketch of the machine is compared with designs of similar machines already drawn up. If no drawing is suitable for the unit on order, a new drive is laid out by a draftsman.

From engineering, the completed design is sent to the stock room, where necessary finished parts are selected. The parts taken from the stock room are divided into two classes: those which go directly to assembly, and those incorporated into the column in the welding department.

The basic drive is built in the welding room. It is then ground and taken to the assembly department. Here the various pieces of finished stock are added. The drive is painted with machinery enamel, crated, and shipped. This whole cycle can be completed in a day if the drive is a more or less standard type.

The motor drives manufactured by this company can be divided into three main classifications.

1. Welded steel box section columns.
2. Structural square tubing assemblies.
3. Flat panel supports.

The manufacture of each of these three types presents individual problems which will be considered separately.

Welded Steel Box Section Columns—Columns built by this company are made from $\frac{3}{16}$-inch and $\frac{1}{4}$-inch hot-rolled plate. When drive parts go to the welding room, a template of the column accompanies them. The side panels of the column are cut to the shape of the template by means of a flame-cutting pantograph specially built for the purpose.

The two side panels are cut separately, lightly tacked together, and ground smooth. An attempt was made to stack-cut the plate, but it was not economical for our purposes. The wide mill plates are somewhat wavy, and it was necessary to clamp them together so carefully that the additional expense more than offset the saving in cutting time.

After they are ground, the two side panels are set up in a jig and tack welded to the base plate and head piece. Sheared plates of the correct width are bent and then tacked to the side panels to complete the box section. Tacks are made every three or four inches in order to minimize distortion from welding. If the column is very large, internal bracing is added before the tacking operation is completed. The bracing eliminates any tendency for the column to weave or vibrate under load. For drive sizes under $7\frac{1}{2}$ horsepower, internal struts are rarely used.

After tacking, the column is welded up. On heavy fillets, like that which joins the column to the base plate, a $\frac{3}{16}$-inch fillet rod is used. This gives a beautiful, smooth, concave bead which requires no finishing. The fillet is usually completed in one pass. The column proper is welded together with a poor fit-up rod $\frac{5}{32}$ inch in diameter. The corner welds are completed in one pass, downhand, by the use of a small circular weave, which makes a smooth weld requiring less grinding. The top end of the column fits around the head piece, usually a length of tubing or pipe of various diameters. This head piece is welded to the column by means of a figure eight or long weave weld.

There is no advantage in using a deep penetration rod for this work. No stress approaching the tensile strength of the metal is ever applied to a column. Furthermore, a "hot" rod tends to burn through in spots where fit-up is not good. Coated rods are used to obtain greater ductility and purity of weld metal. Ductility is very advantageous in tacking, for the tacks can withstand considerable abuse from a hammer.

Columns were formerly welded up on benches with chocks of various sizes to hold them in place. A work positioner was recently completed which allows the welder to complete a column without the difficulty of hand positioning. This fixture will be further discussed under costs in Part IV.

The problem of work distortion due to the contraction of weld metal is not serious. Columns are well tacked and the weld does not pull them noticeably. Careful welding in a set sequence controls distortion to a large extent. Opposite corners of the column are welded first, then the base plate, and finally the head piece. If a plate bows to any extent it is straightened in an air press. On close work the weld is stressed with an air hammer. This is not a common occurrence, since it is rarely necessary to work closer than $\frac{1}{8}$-inch. Only one application is hampered by distortion, and it will be discussed under Part II of this section.

Structural Square Tubing Assemblies—Drives are often built from structural square tubing. This method of construction is very inexpensive. Box sections are already provided in the tubing, and the only welding required is in butt welding the lengths of tubing together with the poor fit-up rod mentioned above.

Fig. 6 shows to good advantage one of the methods of belt adjustment used by this company. This method of adjustment is also used on box section columns. Welded to the motor plate is a piece of cold drawn steel, or ground steel tubing with or without acme threads, depending upon the particular application. This piece is provided with a $\frac{1}{2}$ x $\frac{1}{8}$-inch keyway. The whole sub-assembly fits into a socket of seamless tubing. After the two assemblies have been lined up, a $\frac{1}{2}$ x $\frac{1}{8}$-inch key is welded to the female assembly. This is accomplished by bending the last $\frac{1}{4}$-inch of the key to a right angle so that the ends project through two $\frac{1}{2}$-inch holes drilled near the ends of the tube. The $\frac{1}{2}$-inch hole is then filled with weld metal, immobilizing the key.

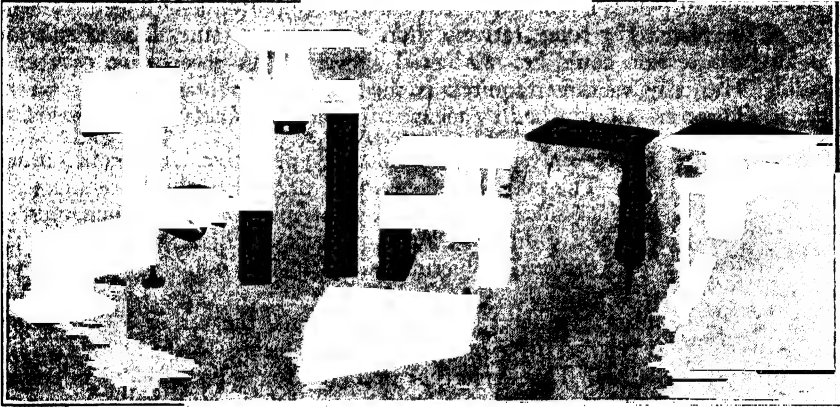



Fig. 8. Special drive units built for punch presses.

Engineers have sometimes been surprised that such an arrangement is strong enough to withstand the torque to which the units are subjected. They point out that the welding rod has barely begun to work by the time the hole is filled up. As a result, the weld is impure. This is a valid criticism. The only possible answer is that in upwards of 1500 applications, some of which have been in use for five years, not one failure has been recorded.

Distortion due to welding detrimentally affects only this sliding tube assembly. The female member is pulled out of round by as much as $\frac{1}{32}$ inch. It is consequently necessary to ream out each tube after it has been welded. The cost of this operation is not excessive, as is shown in the various cost sheets presented. A large radial drill with special chucks and fixtures is used for the job.

Structural square tubing is surprisingly strong. It has been used on drive units up to 15 horsepower in size. Compared to a column of the same section welded up from $\frac{1}{4}$-inch plate, the tubing is about 60 per cent cheaper. Its use is restricted to short spans and vertical members, as shown in the various illustrations. From a sound engineering standpoint, square tubing does not make a true application, since the transverse axes of the tubing are of the same length at both top and bottom. This is not an important drawback.

Flat Panel Supports—The third main classification of drives embraces those units whose main supporting members are flame-cut from $\frac{1}{2}$-, $\frac{5}{8}$-, $\frac{3}{4}$-, and 1-inch plate.

The largest drive ever built by this company is of this type. It was made from a panel of 1-inch plate with stiffeners welded across the bottom side. The drive stands in a horizontal plane and is held in place by four adjustable screws, which in turn are welded to vertical pads of $\frac{5}{8}$-inch plate bolted to the machine.

Our use of panel sections came as a result of an attempt to cut the cost of large planer drive units. The two vertical support members which rest upon the curve of the planer yoke were formerly made in box section. In February 1941 these two sections were replaced by panels of $\frac{3}{4}$-inch plate, flame-cut and ground to the correct shape on a test model for our own planer. The new type of construction proved to be every bit as rigid as the original, and a saving of 25 per cent in manufacturing cost was made.

The use of panels is restricted. Excessive unsupported length leads to bending of the plate. For comparatively short sections, the panel is as satisfactory as any box section could be. As noted above, it is a cheap type of unit to build. The only welding required is the mounting of various pads on the panel. These are all attached by means of positioned fillets or butt welds.

Part Four—Cost Analysis of a Standard Type Drive Unit from January 1940 to May 1942—The major obstacle in an attempt to show complete cost-records of our product since 1940 is the great mass of data which must be presented. Since so many different kinds and sizes of drives are built by this company, a comprehensive cost picture is nearly impossible to make, except on the most general grounds.

In order to present a short, true, cost analysis, the writer has chosen to give data on one type of drive only: the gear transmission drive for standard 14 and 16-inch lathes. This drive type accounts for approximately one-twentieth of the production volume of this company.

In all the breakdowns that follow, no overhead or selling expense is included. No sheaves, belts, electrical equipment, gear boxes, or finished materials such as nuts and bolts are considered. All the material costs, excepting that of cast iron, are based upon quantity purchases at today's market prices.

The first model of the drive to be analyzed was built in February 1940. (Fig. 7). The engineers believed that economy would be obtained by the modification of an existing drive type. Accordingly, one new casting was designed and added to a drive style already in production. This proved to be an expensive economy. The drive worked very well and its appearance was excellent, but the cost of manufacture was excessive. Its production was discontinued after six units were sold.

Cost Data for Drive No. 1087 (Fig. 7)
February 1940

Item	Quantity		Rate		Amount
Material					
5 Castings	52#	@	$ .07		$ 3.64
3/16" Steel Plate	37#	@	3.65	per cwt.	1.35
Seamless Steel Tubing	5"	@	63.92	per 100'	.27
8/16" Steel Plate	8#	@	3.65	per cwt.	.29
Miscellaneous Items (Handwheel, Bushings, Pins, etc.)					2.40
Total					$ 7.95
Labor					
Cut	.5 Hr.	@	$ .80		$ .40
Weld	4.2 Hr.	@	.80		3.36
Grind	1.0 Hr.	@	.50		.50
Machine Work	5.6 Hr.	@	.65		3.64
Assembly	2.1 Hr.	@	.60		1.26
Total					$ 9.16
Total Material and Labor					$17.11

The next design, Fig. 8, worked out swung in the opposite extreme. In an attempt to cut costs, a drive of inferior characteristics was produced. There were two drawbacks to the new design. First, when the take-off belt to the machine was adjusted, it automatically changed the centers on the V belt input

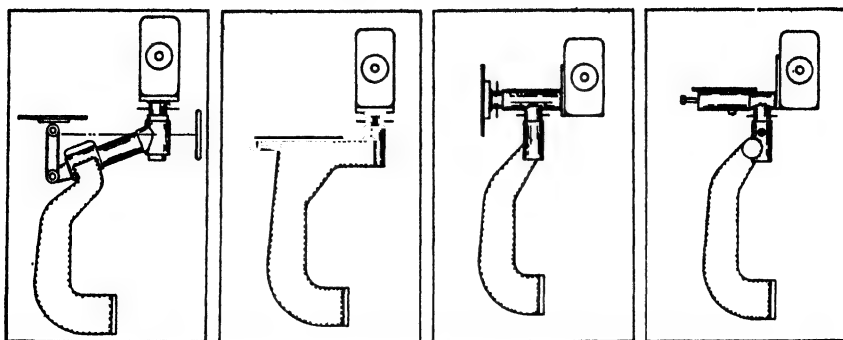
drive, necessitating double work to tighten one belt. Second, the column was of a top heavy and unwieldy appearance. The first of these drives was built in July 1940 and only two of the model were produced.

Cost Data for Drive No. 1364 (Fig. 8)
July 1940

Material				
1 Casting	16#	@	$ .08	$ 1.28
3/16″ Steel Plate	56#	@	3.65 per cwt.	2.04
Seamless Steel Tubing	6″	@	63.92 per 100′	.32
1 Bronze Nut				.44
Total				$ 4.08
Labor				
Cut	.6 Hr.	@	$ .80	$ .48
Weld	3.8 Hr.	@	.80	3.04
Grind	1.2 Hr.	@	.55	.66
Machine Work	2.5 Hr.	@	.65	1.62
Ream	1.4 Hr.	@	.62½	.88
Assembly	.8 Hr.	@	.50	.40
Total				$ 7.08
Total Cost, Material and Labor				$11.16

Since this design did not prove successful, an immediate change was made in the basic design. Both the motor and transmission were mounted on the same vertical adjusting screw, (See Fig. 9). This eliminated the necessity of adjusting both sets of belts at the same time. The bulky column was also discarded. Figures for this drive, a good model, which was first built in August 1940 show an increase in cost. The advanced design more than offset this increase.

Cost Data for Drive No. 1479 (Fig. 9)
August 1940

Material				
1 Casting	16#	@	$ .08	$ 1.28
3/16″ Steel Plate	40#	@	4.40 per cwt.	1.76
¾″ × 6″ H.R.S.	11#	@	3.65 per cwt.	.40
Seamless Steel	15″	@	63.92 per 100′	.78
2½″ Iron Pipe	9″	@	23.54 per 100′	.17
1 Bronze nut				.44
2½″ rd. C.D.S.	10#	@	5.04 per cwt.	.70
Total				$ 5.53
Labor				
Cut	.5 Hr.	@	$ .80	$ .40
Weld	3.6 Hr.	@	.80	2.88
Grind	1.0 Hr.	@	.55	.55
Machine Work	3.4 Hr.	@	.65	2.21
Ream	1.2 Hr.	@	.50	.60
Assembly	1.2 Hr.	@	.65	.78
Total				$ 7.42
Total Cost, Material and Labor				$12.95

(Left to right): Fig. 7. Design #1, gear transmission drive. Fig. 8. Design #2, gear transmission drive. Fig. 9. Design #3, gear transmission drive. Fig. 10. Design #4, gear transmission drive.

A number of drives of this type were built in the period from August to December 1940. No appreciable reduction in cost was noted during this period.

In October 1940 a new design, (See Fig. 10), for the medium size gear transmission was decided upon, and became the unit which has been manufactured from that time to the present. We have been unable to improve upon this design, and emphasis has been placed upon an attempt to standardize shop procedure. This has met with a measure of success, as can be seen in a cost comparison of the first drive of the type and a similar one built in April 1942.

Cost Data for Drive No. 1826 (Fig. 10)

Material

Item	Quantity		Rate	Amount
3/16″ Steel Plate	36#	@	$ 3.65 per cwt.	$ 1.31
Seamless Steel Tubing	14″	@	63.92 per 100′	.76
2½″ rd. C.R.S.	20#	@	5.04 per cwt.	1.40
2½″ Iron Pipe	8″	@	23.54 per 100′	.15
½″ × 8′ Bar	8#	@	4.75 per cwt.	.38
¼″ Plate	8#	@	4.75 per cwt.	.38
1 Bronze Nut		@	.44	.44
Total				$ 4.82

Labor

Operation	Time		Rate	Amount
Cut	.5 Hr.	@	$ .85	$ .42
Weld	3.8 Hr.	@	.85	3.23
Grind	1.0 Hr.	@	.55	.55
Machine Work	2.6 Hr.	@	.65	1.69
Ream	1.0 Hr.	@	.55	.55
Assembly	1.3 Hr.	@	.65	.84
Total				$ 7.28
Total Cost, Material and Labor				$12.10

Cost Data for Drive No. 2840

Material

5/16" Plate	35#	@ $ 4.60	per cwt.	$ 1.61
3/4" × 6" H.R.S.	11#	@ 3.65	per cwt.	.40
2½" Pipe	8"	@ 23.54	per 100'	.15
Seamless Steel Tubing	14"	@ 63.92	per 100'	.76
2½" round C.D.S.	20#	@ 5.04	per cwt.	1.40
½" Plate	8#	@ 4.75	per cwt.	.38
½" × 8" Bar	7#	@ 4.75	per cwt.	.33
Total				$ 5.03

Labor

Cut	.5 Hr.	@ $1.00	$ .50
Weld	2.7 Hr.	@ .85	2.29
Grind	1.0 Hr.	@ .55	.55
Machine Work	1.4 Hr.	@ .70	.98
Ream	.8 Hr.	@ .60	.48
Assembly	.8 Hr.	@ .70	.56
Total			$ 5.36
Total Cost, Material and Labor			$10.39

The decreased labor costs shown in the last example are the result of standardization of procedure and improvement in jigs and fixtures.

After the first unit proved a success, a group of detail drawings were made showing the exact construction details of the five sizes of upper assemblies built. The drive columns were built in the same fashion as they always had been.

Jigs for welding the upper assemblies were soon devised, and they were made in quantities of ten instead of individually. Machined pieces were turned out in lots of thirty.

When it became apparent that no further cost reduction could be made in the upper assembly, attention was turned to the manufacture of columns. Twenty standard column designs were laid out. A new jig for building columns was made, and a positioner for welding them was devised.

The jig and positioner deserve mention. The column jig consists of a horizontal bar of cold drawn steel which carries a slide. On the slide is mounted a vertical screw with a clamp that holds the head piece of the column. The head piece can be lifted any desired distance by turning a handwheel on the screw. A steel rule is provided for measuring off the desired height. The horizontal steel bar is also provided with a rule which allows the welder to set the jig to the correct length in a moment's time. At the other end of the jig is another vertical screw which carries a flat machined plate upon which the column base plates are clamped. This screw is also provided with a rule and handwheel. Center lines are automatically determined by gauge bars which fit over the length of cold drawn steel.

It has been found that fit-up time on any column has been reduced by approximately 15 percent by the use of this new jig. The saving amounts to a sizeable sum, since fit-up takes much longer than the actual welding.

More recently, a work positioner was completed. An old tilting tumbling barrel was provided with a fixture for holding columns which replaced the

barrel. A brake was placed on the axis of rotation. The use of this positioner cuts welding time by about ten percent, mainly because the welder does not need to move the column around on a table and block it up to different positions. Experiments are being made at the present time with vertical down welding of the column corners, and this may further cut the welding time, although the amount will be very small.

Breakdown of the figures given above shows that the cost of the first transmission drive was 39 percent more than the cost of the last example given. This is hardly a fair comparison, since the first unit employed the use of expensive castings and machine work. The most important point to consider is that a better looking, cheaper, and more efficient drive was eventually worked out, and that in the latest model, arc welding is employed exclusively.

After the drive type was frozen, the comparison of costs in the last two examples shows that refinement in procedure has made possible a cost reduction of 14 percent, even though labor costs have risen by 7 percent.

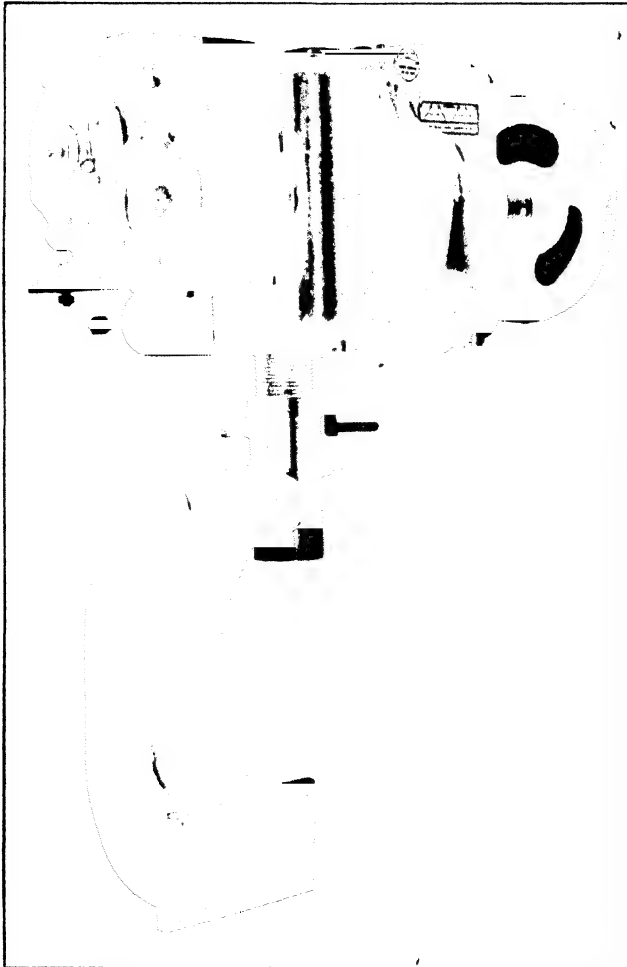



Fig. 11. Standard gear transmission drive.

In the cost accounting system used by this company, engineering time is considered as overhead. Two different periods were analyzed in an effort to determine the cost of engineering; the first three months in 1940 and the first quarter of 1942. An interesting point was established. In each period, the cost of engineering was $1.37 per drive unit. On a percentage basis the earlier engineering cost was 1.05 per cent of the sales price of the drive, and the later cost was 1.02 per cent of the price.

This is a low figure when it is considered that the engineers make new drawings or adapt old ones for every drive which enters the shop. The writer has been told that engineering expense necessary in the employment of arc welding for motor drives is excessive. The experience of this company does not confirm this statement.

An estimate of the total savings effected by this company in the last year as a result of the improvements listed above, can easily be made. On the gear transmission type drive, (See Fig. 11), the savings amount to approximately $2242. Savings accruing from the use of improved techniques and designs in the manufacture of our other drives are not so large. They have been in production for a longer period of time, and the standardized design types have been worked out. A 5 per cent reduction in manufacturing costs has been offset by the increase in wages. The saving, however, is approximately $8000 per year.

Part Five—Conclusion—This paper has attempted to show the benefits derived from the use of arc welding in the manufacture of motor drives. The conclusions drawn, in order of their appearance in the paper, are here stated as briefly as possible:

1. Important benefits to industry result from the use of motor drives.
   a. Machines can be placed to best advantage.
   b. Speeds are corrected.
   c. More power is transmitted.
   d. Psychological benefits of a cleaner, lighter plant lead to increased production.

The result of these factors is a productive increase of at least twenty percent per machine. On the assumption that 25,000 machines have been motorized since 1940, each machine now makes $2.50 per hour. Total earnings of the motorized machines have been $130,000,000 a year. Twenty percent of this total can be ascribed to motorization, a sum of about $62,800,000, in the period from January 1st, 1940 to June 1st, 1942. Arc Welded drives can be considered to directly account for 15 per cent of this total.

2. If all motor drives used by industry were arc welded, the probabilities are that production would further be increased, since arc welded drives are more efficient. Furthermore, the expense of installing a standardized drive is probably 25 per cent of the cost of the unit, while the installation expense of an arc welded drive is nearer 15 percent. This is because the drive is built to fit the machine.

3. This company originally built drives from cast iron. A saving of 15 percent in manufacturing costs was made when arc welded steel drives replaced the cast iron types.

4. The use of cast iron in drive columns is not sound engineering practice.
   a. Cast iron columns must be more bulky since the material is not as strong as steel.

b. Cast iron columns are usually of the wrong cross section, since box section columns are difficult and expensive to cast.

c. The necessity of standardization to cut pattern costs leads to the cast column being inordinately deep and long, which affects its performance adversely.

d. Welded steel allows a flexibility not obtainable in cast iron. Therefore, drives for machines of any description can be built.

5. This company recently attempted to devise a cast iron drive with all the features of our standard welded steel column. The experiment was unsuccessful. The cast drive, in an effort to make it of good quality, cost 34 per cent more than the equivalent steel drive.

6. If all drive manufacturers were to build drives from welded steel, they would realize a saving of 15 to 20 percent a year, if their experience were the same as our own. This cannot be stated categorically, however, since their costs, due to certain limitations in design, are probably lower than our own were.

7. Manufacturing costs of standard drive unit manufactured by this company show a reduction of 39 per cent in the period from January 1st, 1940 to May 1st, 1942. The reasons for this reduction:

a. Improvement in design, with the elimination of castings.

b. Improvement in manufacturing procedure by means of quantity production of standardized sub-assemblies and the use of better jigs and fixtures.

8. The savings which were realized from the improvements in design and construction amount to approximately $2,242 a year for this type of drive.

9. The total savings due to improvements in design and construction of all the products of this company amount to approximately $10,242 in the past year. This is proportionately less than the savings recorded in the example given, since most of our products have been built for a longer period of time and consequently construction procedures were further advanced.

The major conclusion which may be drawn from this paper is: For the motorization of machine tools, no type of construction yet devised can equal the welded steel bracket, in point of view of breadth of application, maximum strength, and economy of materials and construction.

Chapter XX—Welded Steel in Paper-Making Machinery

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R. S. Conabee

Subject Matter: By welding, the surface irregularities of riveting and subsequent lumping of pulp were eliminated. A welded open "C" supporting framework with "kickout" blocks permitted easy replacement of Fourdrinier wire. In welded design, suction boxes become integral with beam section of framework, thereby adding to strength. These are separately mounted in cast iron units. Uniform drying necessary for uniform paper. This is successfully accomplished by forming a steam drying drum from separate steel sheets welded together—a real welding accomplishment. Design could be changed during fabrication in a welded unit. Weight and cost data broken down. Savings up to 77 and 130 per cent suggested.

To the welding fabricator, the paper-making trade is a relatively uncharted territory. In order to invade this territory, the welding fabricator must make himself familiar with the problems confronting the paper maker and the paper machine fabricator in order to functionally adapt his weldments.

The paper machine tender learns his trade over a long period and is inclined to the viewpoint that the difference between good paper and poor paper lies entirely in his skill, and that the machine itself is secondary. I do not contest this. The situation, however, has hindered the progress of the machine parts in keeping with the progress in other fields. An experienced paper maker said, at the recent meeting of the Technical Association of Pulp and Paper Manufacturers, that relatively little progress has been made in the science of making and drying paper in the last fifty years. The same can be said of the paper machine.

In this field as in others, there has been an ever increasing demand from management for greater production. Existing paper machines have been speeded up by the adoption of more modern power plants and drives, and by increasing the efficiency or numbers of drying cylinders of the machines. The tendency in paper machine manufacturers has been to wider spans and higher speeds. With the increase in span and speed, the conventional machine structures, especially in regard to materials, are beginning to show design limitations. Manufacturers are beginning to turn to steel in order to satisfy the demand for stiffness and strength required in the new machine structures. Welded steel, incorporating large sized predictable structures, with a high strength to weight ratio, furnishes the best answer to these problems.

Our company, a welding fabricator, has been for some time producing steel dryers that enabled machines to step up their drying capacity as machine speeds were increased. Recently, having with us a paper machinery and paper making expert, we obtained a far-sighted customer willing to take a chance on a new design and a new material in an all-welded steel paper machine. I was fortunate enough to draw the assignment of designing

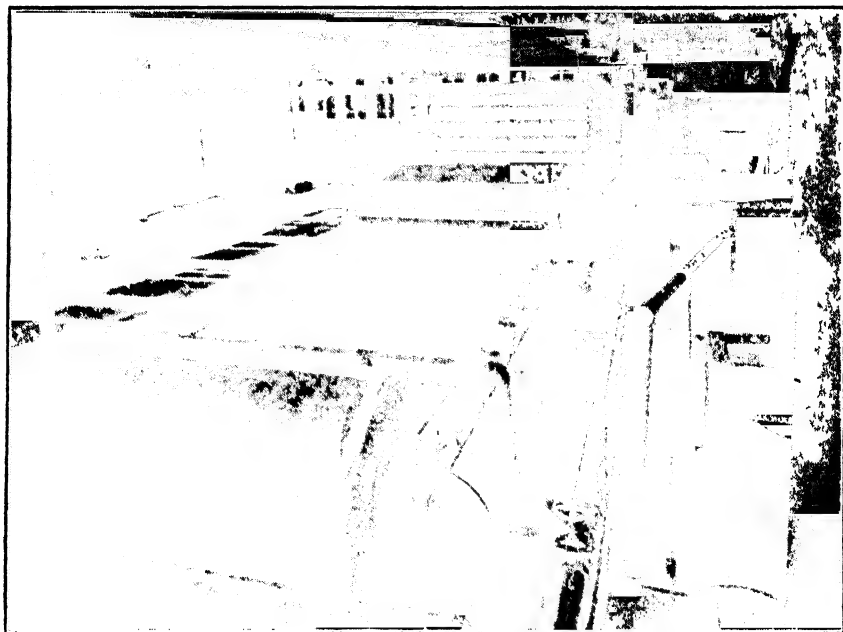



Fig. 1. The subject of study.

the welded steel parts necessary for the machine, (See Figs. 1 and 2). I cannot claim that all the design on the welded steel elements is my own—a great portion of it was developed from the best ideas drawn from a number thrown in a hat, as most machinery is designed.

I do not intend to go into the principles of making or welding the paper machine parts—enough material can be found in any handbook or drawn from the fabricators' experience for that. At the same time, digressions made into the paper making processes may sound like McGuffey's "First Reader" to the paper expert. The principal intention is to demonstrate to the welding fabricator that welded steel is admirably suited to the making of paper machinery.

While the primary intention of this paper is to present the advantages of welded steel in the paper making field, it will be helpful to go into the actual operations in the making and drying of paper in order to understand the job assigned to the welded parts. The operations noted in the subsequent paragraph may be traced through the machine by following the lettered symbols on the assembly print, Fig. 3.

Briefly, the machine is of the Fourdrinier type in which the paper stock, an extremely dilute suspension of pulp fibres in water, is directed (A) onto a moving fine mesh wire screen, (B) most of the water passing through the screen, depositing a thin film of wet pulp on its surface. The wire passes over suction boxes (C), which drag out part of the moisture as it passes to the couch rolls (D), where a steam drum on the upper side of a felt picks up the film on the felt surface. Another felt strip is passed up to the exposed side of the film and the resulting sandwich squeezed by a press roll (E), removing more of the moisture. The film is then plastered up

against the first Yankee dryer by a rubber covered roll (F) where it remains by itself, the felts returning over a series of rolls where they are sprayed to remove any fuzz remaining, removing the excess moisture by suction (G).

The paper film on the drum is rapidly dried and scraped off at (H) by a bronze blade, a process called "creping". The paper is now led over the secondary dryer (I) on its reverse side where the drying process is completed. On the secondary dryer, the paper is held into close contact by means of a tight felt.

The paper is now led through the calendar (J), an "ironing" operation on a steam drum, thence to the reel (K) and wound on a spool. Processes (L) and (M) illustrate unwinding two rolls into one sheet passing over a slitter roll, where it is score cut into desired widths, and rewound onto reels.

The machine is designed to produce a wide range of light papers, among which are toilet tissue, napkin stock, facial tissue, light waxing stock, light M.G. papers, etc.

Paper machinery manufacturers will note that the machine is quite compact. Many modern machines producing equivalent grades of paper occupy from two to three times the space of this machine, and have a proportionate increase in the number of parts, drying drums especially, required.

In presenting the adaptation of welded steel to the welding fraternity, it will be necessary to go into these processes more thoroughly in order to demonstrate the functional design principles involved.

The Fourdrinier Section—The first operation of the Fourdrinier, that of directing a stream of paper stock onto the moving wire, is one of the most delicate and most important in the whole paper making process. It is essential that this stream be of constant cross section, velocity and consistency throughout its entire width in order to insure a sheet of uniform quality and caliper. This is evident from the fact that each fiber is compressed and dried into paper in its relative position as deposited on the wire.

The flow spreader designed for this job was constructed in three sections plus two end supports in order to facilitate machining. It would be quite feasible to fabricate the structure as a unit, but the machining problems

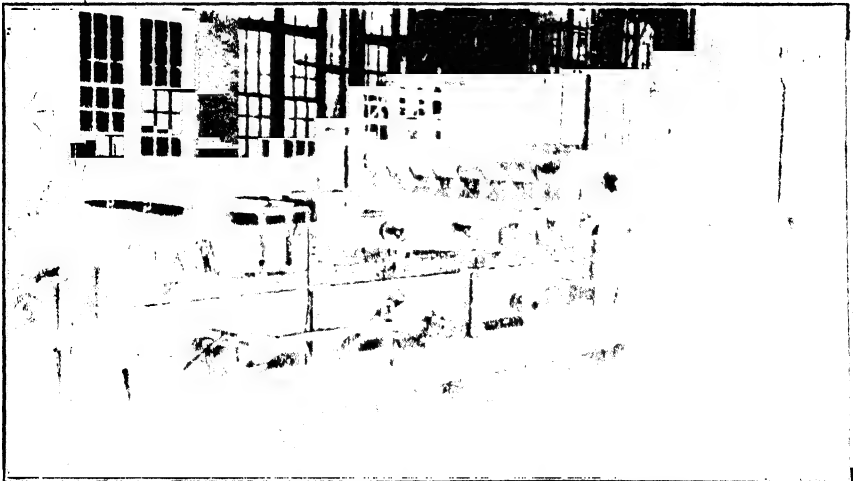



Fig. 2. Table roll frame supported on open structures.

would be prohibitive. Prior to machining, the three flow sections were hot dip galvanized to prevent corrosion.

Referring to the photograph, (Fig. 1), the stock is pumped into a large compartment which slows down the flow, permitting the stock to spread and develop an even pressure head across the entire width of the chest, and breaking up any tendency toward "streaking". The velocity is built up again as the flow rises through a passage that is gradually restricted in the direction of flow. At the height of its rise, the direction of the flow is changed abruptly and directed downward onto the wire. The resulting centrifuge develops a turbulence which effectively distributes the paper fibers, and insures complete and uniform filling of the passage as the stream is directed downward onto the wire.

The stock passage is entirely unrestricted through its entire length from pump to wire. This condition, while ideal from the flow standpoint, presents structural problems that are best met by a stiff welded steel construction. Pressure variation, or surges, tend to belly the nozzle outward, which tendency is greatest in the center due to restraint at the end, and since they may not be tied together, must be supported independently. To this end, twelve inch steel pipe is used as a beam over the upper lip and below the lower, and connected to their respective lips by ribs.

Thus they support the plates which form the nozzle and offer the most effective resistance to the bellying action of the nozzle, since deflection in this direction must distort the tube torsionally. The efficacy of this construction was demonstrated by producing a glasslike film of pulp on the wire without the conventional screw adjustment on the lip, (See photograph, Fig. 2).

The pipes are welded at their ends to a connecting plate which forms the side of the nozzle passage and furnishes a bolting flange to the end supports, note "A1" on Fig. 3, which hold the nozzle assembly as a cantilever out over the wire. These supports, which also are shown in Fig. 1, are simply and inexpensively produced as a single gas cut plate with pads welded to the feet to serve as bolting flanges.

The moving bronze wire screen upon which the paper film is formed, is supported at the ends by rolls, on the top by intermediate table rolls, and tightened underneath by a stretch roll arrangement.

The rails which support the table rolls were constructed of bent channel sections which furnish a concealed bolting surface, and braced laterally by an "X" frame as shown by Fig. 4. Note the inverted "V" section of the cross bracing member which allows smooth drainage from the wire to the collector pans hung from the framing. This is important from the standpoint that any shelving or projections allow the pulp fibers to collect and drop off in concentrations, resulting in irregular consistencies when recirculated.

It would be impossible here to duplicate these sections and span in castings; and a riveted structure would involve surface irregularities resulting in the undesirable pulp concentrations noted previously.

The provision made for changing the wire is unique on the welded steel framing. Ordinarily, the rolls carrying the wire are moved out of their framing by a complicated auxiliary equipment and held free while the wire is changed. This entails a considerable amount of time as well as providing and maintaining auxiliaries.

In the welded steel framing, the table roll frame is supported between two rectangular open structures, the upper beam of each supporting on its outboard side, the end wire rolls, as shown by Figs. 2 and 4. Note from

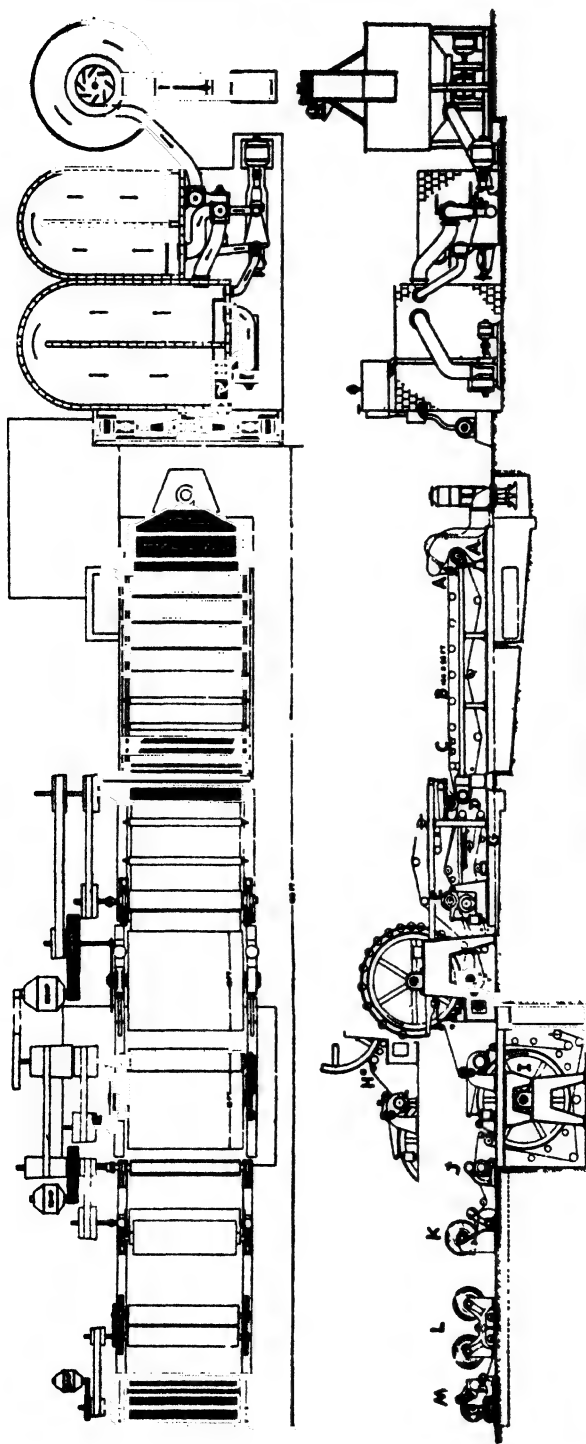



Fig. 3. Machine assembly.

Fig. 3 that the wire passes through the open center of the supports, totally enclosing the upper beams within the wire.

When operating, the front rail supports and "kick out blocks", noted in phantom on Fig. 4, are in place, forming a closed and stable frame. When it is necessary to change the Fourdrinier wire, these pieces are removed, allowing the wire to be slipped off and replaced over the entire roll assembly without obstruction.

This feature presents design complications that were effectively met by welded steel. It will be noted that the end reactions of the couch roll, table rolls and rails, suction boxes, bearings and miscellaneous machine parts, are supported by what amounts to an open "C" frame when the front blocks are removed. The total reaction amounts to approximately 9000 pounds, distributed 7000 pounds to the couch end and 2000 pounds to the breast roll end. The end reaction of the couch roll, being outboard of the support, imposes an additional torsional moment. Neglecting torsion, this structure can be compared to a 3½-ton "C" frame with an open throat of 155 inches.

To provide this support, the frame illustrated in Fig. 5 was developed, incorporating a box section because of the torsional load. The side plates were gas cut from sheared rectangular plates; the top and bottom flanges and the throat members were universal mill rolled flats.

The two flanges and the internal ribs were designed to constitute a rigid truss, as shown in the lower left hand corner of Fig. 4, and further reinforced by the side plates as shear members. Stresses were kept low, approximately 4,500 pounds per square inch, in order to have little deflection.

The flat plate frame shown in Fig. 6 was developed to perform a similar function on the breast roll end of the frame. A flat plate is suitable here since the torsional moment is negligible and the total reaction at this end comparatively light. The economy of such a structure using a single gas cut plate as the principal member is apparent.

Design Comparison of Cast Iron and Steel in the Couch Roll Support, (Fig. 5)—The following computations for the welded steel couch support have been simplified for a quick comparison with a cast iron frame having the same stiffness characteristics within the same space limitations.

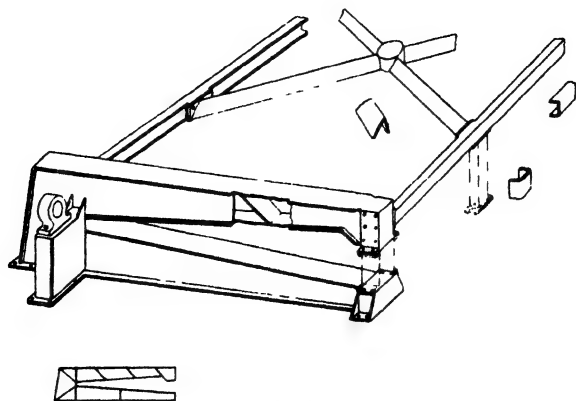
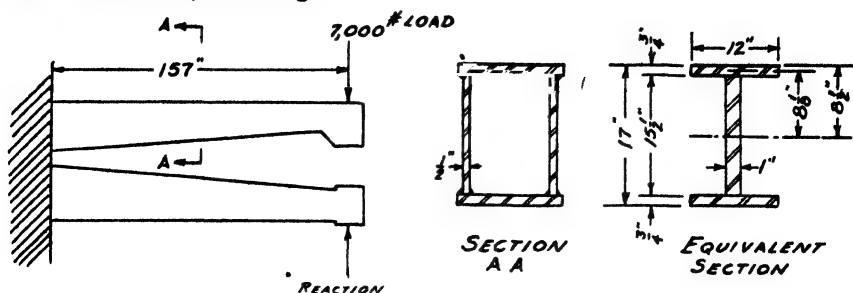



Fig. 4. Rails constructed on bent channel sections.

The deflection is based here on the average beam section loaded as a cantilever, neglecting deflection in the throat section and restraint of the rear hold down bolts, and weight.

Then:

I (each section) =

$$Ay^2 = 2(12 \times \tfrac{3}{4})\,(8.125)^2 = 1{,}188$$

$$\text{Plus } \frac{bh^3}{12} = \frac{(15\tfrac{1}{2})^3}{12} = 310$$

$$= 1{,}498 \text{ "}4^{th}$$

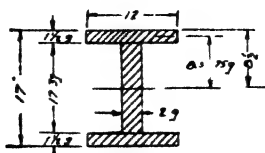
And deflection of both cantilevers $= \dfrac{2FL^3}{3EI}$

$$\frac{2\,(7{,}000)\,(157)^3}{3\,(30{,}000{,}000)\,(1{,}498)} = 1\tfrac{3}{32}\text{" approx.}$$

The actual deflection was less than this as might be expected from the use of the tapered beam section.

To continue with the comparison, if the frame were to be made in cast iron, neglecting weight as previously, the moment of inertia required would be inversely proportional to the elastic modulus involved:

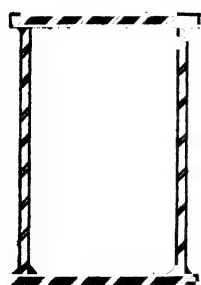
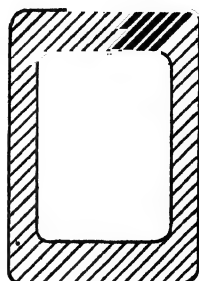
$I = 30{,}000{,}000/\ 12{,}000{,}000 \times 1498 = 3747$ "4^{th}

Because of the wire clearances, top and bottom, the same space limits must be imposed. Then, letting gauge of flange plate equal $1\tfrac{1}{2}$ gauge of side plate as in the steel section, the moment of inertia of the required section will be as follows:

$$\begin{aligned} I\ (\text{flanges}) &= 2(12) \times 1\tfrac{1}{2}\,g)\ (8\tfrac{1}{2} - .75g)^2 \\ &= 36g\ (72.25 - 12.75g + .5625g^2) \\ &= 2600g - 459g^2 + 20.25g^3 \end{aligned}$$

$$\begin{aligned} I\ (\text{webs}) &= bh^3/12 = 2g\ (17 - 3g)^3/12 \\ &= \tfrac{1}{6}\ (4920g - 2601g^2 + 459g^3 - 27g^4) \\ &= 820g - 433g^2 + 76.5g^3 - 4.5g^4 \end{aligned}$$

Adding the two: $I = 3420g - 892g^2 + 96.75g^3 - 4.5g^4 = 3747$ "4^{th}

And solving the equation for g, we find that $g = 1.75$"

The resulting section will have webs 1¾-inches thick, flanges 1½- x 1¾-inches or 2⅝-inches thick, and will result in the same deflection as the steel section with g = ½-inch.

NOTE: Better grades of gray cast iron have an average elastic modulus of 15,000,000. Using this figure, the comparative cast iron section will have 1⁹⁄₁₆-inch webs and 1¹³⁄₁₆-inch flanges.

Suction Box—Suction boxes which remove a portion of the free water from the moving pulp film are mounted on the Fourdrinier rails. As the wire is drawn over the suction box cover, it encounters a series of holes through which water is forced when a vacuum is produced inside the box. The suction box must be quite rigid in order to support this cover in a true plane, since any tendency toward sagging will cause excessive wear of the wire on the high points and poor contacts on the low portions, resulting in a lowered efficiency and a corresponding wet streak in the paper.

In the usual method, the suction box is supported by an independent beam constructed of rolled sections, riveted sheet brass, cast iron, or wood, upon which the suction box of wood or brass is placed.

In the welded design, the suction box is built integral with the beam section and contributes to the stiffness of the structure. The box proper, consisting of a bent channel section together with the bolting flanges for the suction box cover, forms the upper flange of a beam. Note in Fig. 7 that the bent channel has been cut and trimmed so that the section is deeper in the center than at the ends, in order that the box will drain properly. To this channel is welded a web with a pipe at the bottom which serves as the lower flange, as well as to provide a means of exhausting the box and withdrawing water from its center. Thus, none of the structure is parasitic, each part contributing to the stiffness of the structure as well as its function.

As a protection against corrosion, the suction boxes were metal sprayed with bronze before installation.

Standard Section—At this point in the design of framing for the machine, a section was chosen as a standard that would be most satisfactory for the machine. This at first seems to be a minor point, but when it is understood that the section chosen must be used throughout in order that the machine will be uniform and pleasing in appearance, that it must be adaptable from other design considerations, and that it must be capable of economic fabrication—then the selection assumes major proportions.

The box girder section chosen, Section AA of Fig. 8, is the most desirable for the following reasons:

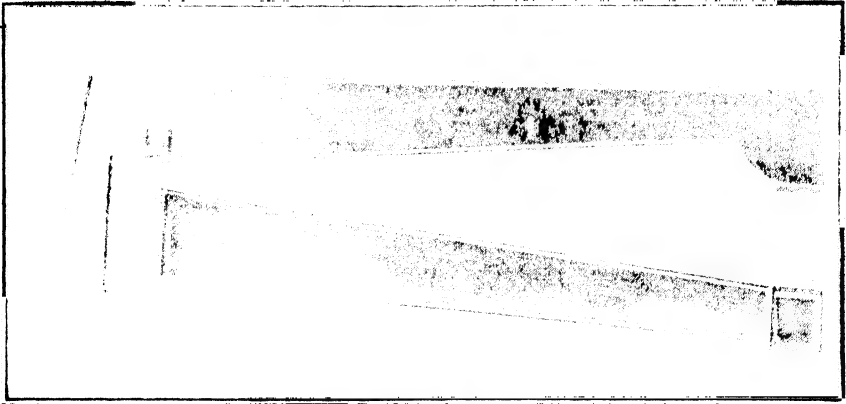



Fig. 5. Couch roll support.

1, The flat top plate can be used for mounting bearings, brackets and other machine elements conveniently, on the center line of the section.

2, The stiffness can be varied over a wide range to suit design considerations while preserving the same outward appearance, by web and flange gauge variation, number and strength of web stiffeners and varying depths of section.

3, The interior of the section can be conveniently used to house moving mechanism as noted subsequently, and to conceal piping and wiring.

4, The members, including the webs, are accessible for welding by leaving the bottom or cover plate off until last.

5, The corner weld to the cover plate can be touched up with a hand grinder to produce the rounded corners desirable for appearance.

6, The bottom plate can be made heavy and extended at the sides to form a mounting surface and bolting flange as shown in section BB.

7, The section matched that of the couch frame already discussed, this frame being practically dictated by design limitations.

8, The section, repeated in a number of frames, is pleasing in appearance. This item is placed last by the engineer, but first by the prospective customer.

Framing—The press frame is a good example of the adaptation of the standard section, shown in Fig. 8. The base portion is built as section BB and the upright as AA, both with the modified corner indicated. The base forms a sturdy support for a heavy chilled iron roll and the upright webs are extended to hold heavy plate rings which form the clevis for the pin of the upper press roll mounting arm shown in phantom in Fig. 8. This arm, incidentally, is gas cut from a single plate and represents a considerable saving in time and money over the usual casting procedure. The gas-cut plate will cost less than the pattern required.

One of the most important functions of the framework is the proper support of the two drying cylinders. The problem here is to support a drying cylinder, pictured in Fig. 9, the press roll, creping mechanism and miscellaneous other equipment such as bearings, air cylinders, totaling no small weight in themselves. The framework must also form a closed system to carry the reaction of the press roll which was designed to produce a force

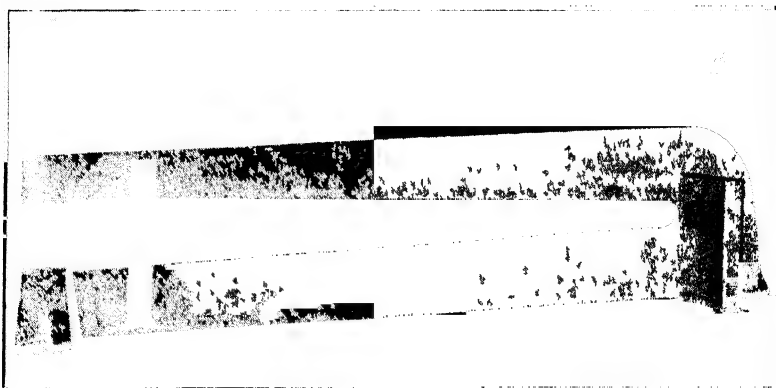



Fig. 8. Breast roll support.

of 250 pounds per linear inch—a total force of 36,000 pounds The whole mechanism to be supported rigidly to hold driving vibrations to a minimum in order to produce a uniform sheet of creped paper.

To perform these functions, the frame shown in Fig 10 was developed, the top surface supporting the main bearing and the actuating cylinder for the press roll. Welded into the webs and lower flange of the leg member are heavy bosses for the pin of the press roll arm. The shelf in front forms a rigid support for the creping and cleaning "doctors" for the dryer The wide span of the bottom supports provides a good footing for the dryer support, the frame being widened out to include the press mechanism and to provide lateral stiffness and mass to absorb driving vibrations.

The web and flange structure alone forms a truss-like framework designed as such to effectively transmit the load to the foot plates, the whole then stiffened by the addition of side plates

The dryer supported by these frames might be said to be the heart of the machine. The pulp film having been made by the Fourdrinier and prepared by squeezing a portion of the free water from it by the press section, is still a moist film without strength It is only when the water is properly driven from this film leaving the interlocking fibers, that paper is produced.

Note the statement, "properly driven" etc. This entails a whole study in itself, and concerns many variables such as type and weight of paper, machine speed, etc, but let it be said here that the porosity or texture of a paper is controlled by the rate at which steam is formed and pushed through the fibers of the pulp film. It is immediately apparent, therefore, that an even surface temperature must be maintained on the surface of the dryer over its entire width and circumference. Internal temperature can be controlled accurately by thermostatic devices, such as is done on this machine, but the production of a uniform temperature on the dryer surface is a mechanical function of dryer design Since the rate of heat transfer is inversely proportional to the mass of the material, according to Fourier's law, it follows that the prime variable is the uniformity of shell gauge and density.

The large diameter dryer, commonly called a "Yankee" in the trade, together with the rubber covered press roll, form a second press section. This differs from the first press in that the wet pulp is pressed tightly to

a hot polished steel surface, giving up six to eight percent of its moisture content (approximately twenty percent of the total water removed) in so doing—and at the same time assuming a smooth and compact finish. Since the finish on the paper is produced by that of the dryer, a superior finish must be produced on the dryer in order to have a superior finish on the paper. This pressing action requires a force of approximately two hundred and fifty pounds per linear inch, which force must be reacted by the shell of the dryer.

The design of the dryer shell, then, boils down to this: It must be uniform in gauge and positively non-porous, since any porosity is in effect a gauge variation that affects heat transfer; and it must be clean and dense enough that a high polish can be applied to its surface by a grinding and lapping process.

Because of the inverse ratio between the rate of heat transfer and the plate thickness, it follows that the shell should be as thin as possible for the greatest efficiency of operation. It must be stiff enough, however, to withstand the concentrated linear load induced by the press roll and keep local deflection to a minimum. In this particular machine, it was determined that a gauge of one and one-quarter inches was the most satisfactory for all conditions. Dryers operating under lesser press loads could have correspondingly thinner shells which would allow greater drying rates.

Steel plates for the dryers on this machine were rolled from selected ingots poured from special heats of a high quality particularly clean steel. The plates were formed on bending rolls to close diametrical tolerances, and the planed beveled edges were welded by a process that matched the hardness of the weld to that of the plate, the welds being X-rayed as an assurance that no porosity here would affect heat transfer.

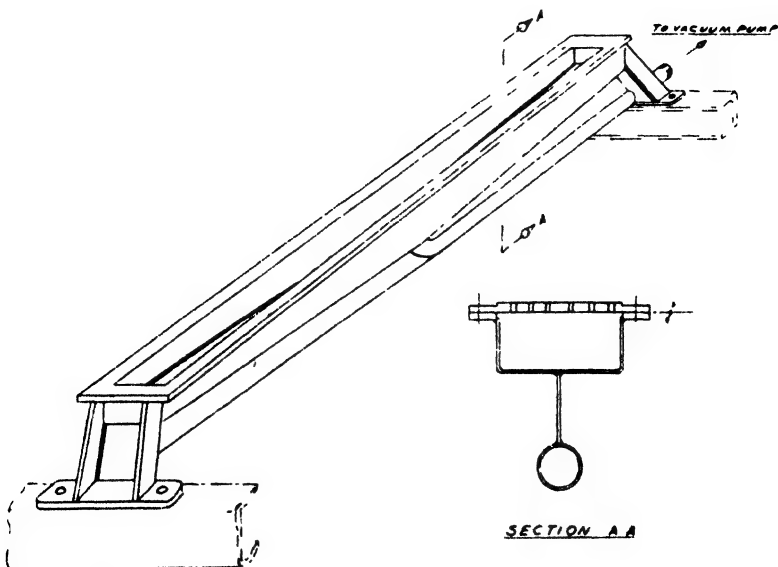



Fig. 7. Bent channel cut and trimmed to greater depth at center than at ends.

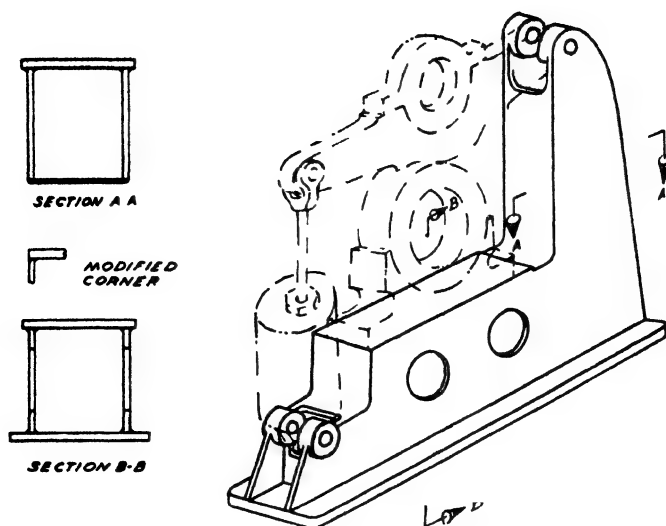



Fig. 8. Use of box girder section.

This shell was welded onto an inner shell to which it connects by machined end rings to preserve its concentricity. These end supports are the only connection to the outer shell, hence there is nothing in the area on which the paper is dried which would be, in effect, a gauge variation and would cause a corresponding temperature drop on the dryer surface. A degree of flexibility is provided by the arrangement that allows the dryer to accurately align itself with the press roll.

An annular space is provided between the inner and outer shells into which the steam is led. Here it condenses, liberating its heat units through the shell to the wet pulp.

The average drying cylinder is nothing much more than a hollow drum in which steam cannot condense efficiently, or rather, rapidly enough for efficient drying. Steam carries with it a certain amount of inert gases which build up in the hollow interior, producing an insulating blanket, unless enough live steam is "bled through" the dryer to drag the entrapped gases with it. This air bound effect is much more pronounced in the large diameter dryers as might be expected since the volume varies with the square of the diameter.

In the annular space between the two shells of the welded steel dryer, steam condenses efficiently since it is impossible for a large band of gases to form. In addition to this, two removal systems are provided to continually draw off the condensate and air, one functioning when the dryer operates below critical with the condensate collecting at the bottom, the other above critical as the condensate is slung around the dryer forming a band about its inner surface.

It has been customary to allow a considerable crown in a rubber covered press roll in order to compensate for unequal expansion rates in the usual

dryer between the center and the ends, because of the solid end construction. Calculations on a twelve foot diameter dryer show that this difference in expansion causes the face to be concave .025-inch which necessitates a crown of .050-inch in the press roll for this reason only. Abnormal wearing conditions resulting from the rubber being crowded sidewise make it necessary to regrind frequently.

The steel dryer designed for this machine, shown in the rough in Fig. 9, incorporates tubular spokes which attach to the comparatively flexible inner shell. Any inequality of expansion in heating up, etc. is compensated by flexure in this member, allowing the outer shell to maintain its press roll alignment.

An inspection of Fig. 9 will disclose that welding is the only feasible means of producing this fabrication. A casting in this form is entirely out of the question; and to build it up of smaller components introduces prohibitive machining and alignment problems.

It is in comparison with cast iron dryers that welded steel design shows its greatest superiority in the paper machinery field. The same physical laws apply to the cast iron dryer . . . density, quality of finish and stiffness directly affect the quality of the paper, and the shell thickness and method of condensate removal have a direct influence on the effective drying rate of the cylinder.

First of all, in order to design for a certain required stiffness, the lower elastic modulus of cast iron results in a thicker shell than is required by a steel dryer. The average cast iron shell is between two and a half and three inches thick, which is determined not only from stiffness considerations, but also by the "Code for Unfired Pressure Vessels" with limitations in steam pressure according to the various state laws.

These factors tending to increase the shell gauge create a vicious circle from the standpoint of efficient operation. All other things being equal, a greater temperature gradient must be supplied to drive the same amount of heat units through a thick shell than a thin one, and conversely, a one-inch shell can transmit twice the heat units than is possible with a two-inch shell.

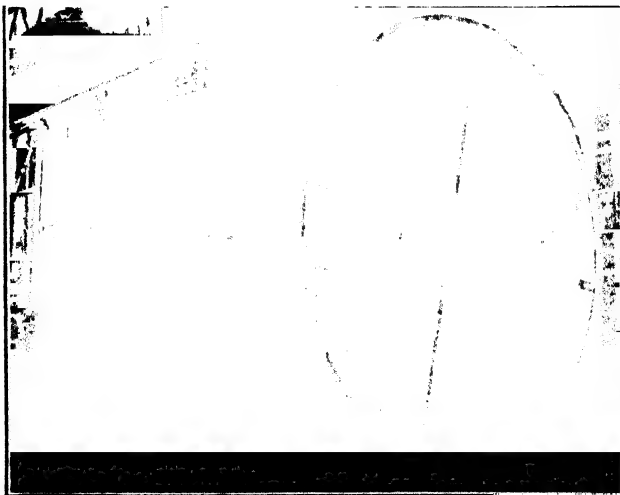



Fig. 8. Yankee dryer.

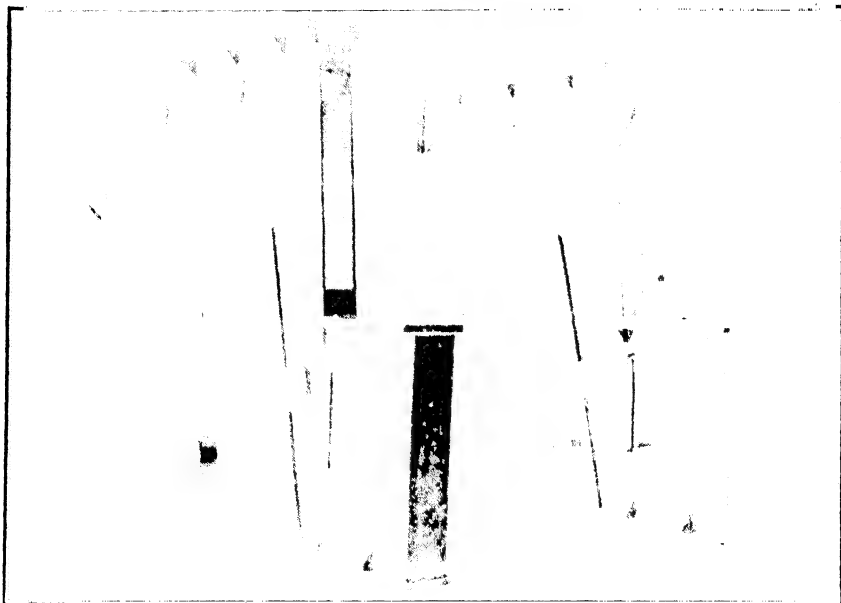



Fig. 10. Main dryer section.

It is this premise which accounts for the compactness of the steel machine. With the attending higher rate of evaporation on the surface of the thinner shelled steel dryers it is possible to do the same amount of drying with fewer cylinders than can be done on the regular paper machine. For a given production, a space and materials economy can be effected—for a given machine, production can be stepped up because of increased drying capacity with steel dryers replacing the cast iron.

There is a distinct difference in the quality of surface between a steel and a cast iron dryer. The steel, having been rolled to gauge from an ingot, has undergone hot work which reduces and refines the granular structure and produces a material capable of taking a high polish. Cast iron, however, is a mechanical composition of graphite particles in iron, and as such is a basically porous structure. No amount of polishing will overcome the fact that the surface is a composite material instead of a uniform chemical composition.

Because of the greater mass of the cast iron dryer, more power must be supplied to accelerate and drive them; and bearings, frames and other machine elements must have proportionally greater capacity.

The secondary dryer was mounted in a pit in order that the opposite side of the paper could be presented to the dryer surface without interfering with the straight-through flow of the paper and at the same time allow a maximum arc of contact. The greatest percentage of drying has taken place on the first dryer; the secondary dryer completes the drying process and improves the surface of the paper that was not previously in contact with the dryer. The secondary dryer is essentially the same as the first and needs no further discussion.

The framing, however, varied since no shelf was provided for creping as on the first dryer stand. Secondary pedestals that form a continuation

of the mounting rails over the dryer bearing were fabricated as separate units to facilitate erection. These two stands and pedestals shown in the rough in Figs. 11 and 12, follow the same design form as the primary dryer pedestals, consisting essentially of the standard section with interior ribs so placed as to stiffen the structure, especially at the inner flange corners, the points of greatest stress.

Flexibility of the Welding Process—During the fabrication of the paper machine weldments, a situation arose that demonstrates the flexibility of the welding process that was actually taken into consideration in the design of the machine. At its inception, the time element did not permit making a complete set of working drawings showing each part of the machine in its exact relation to the others, according to the best practice. It was necessary to begin with a rough draft of the machine showing the principal machine elements only in place, such as dryers, press rolls, Fourdrinier rolls, felt rolls, calenders, reels, etc., and delineating their respective centerlines and clearances.

With this arrangement drawing, the sub contractors furnishing machine elements and the driving mechanism, as well as our shop in its design of the welded components, proceeded concurrently toward the production of the whole. This was done only to meet delivery schedules which would otherwise have been impossible. The weldments were ordered into the steel immediately as designed in order to expedite this schedule. At all times the closest cooperation was maintained between the separate fabricators, but it was foreseen that some interference might be encountered which could be circumvented by altering existing weldments to suit. This faculty of the welding process, then, was utilized to save time.

After the stands had been fabricated, but before machining, it was found that the top surface of one secondary dryer stand had to be extended to provide outboard support for a pinion bearing, the two stands having previously been similar.

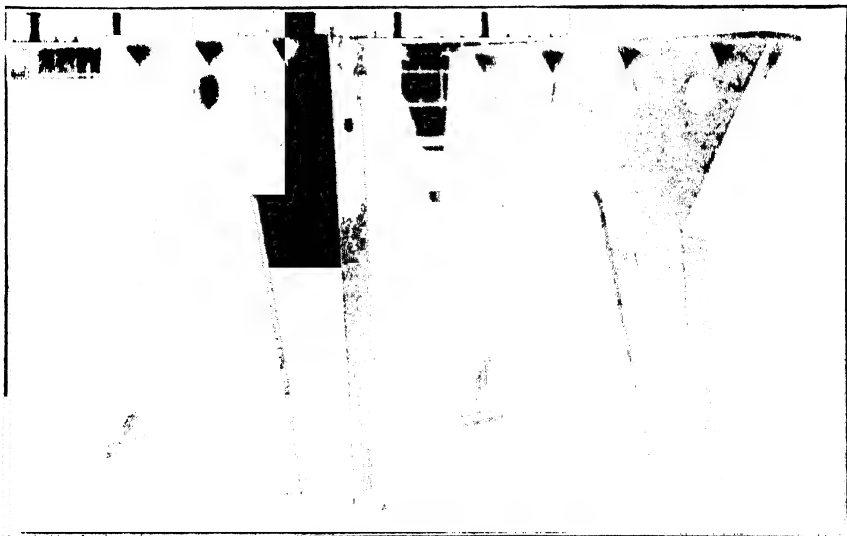



Fig. 11. Secondary dryer stand.

Fig. 12. Pedestal.

In Fig. 13 the process of altering the stand is shown. A part of the end plate and one stiffening rib were gas cut away, a new rib extending to the extremity of the outboard support was provided, and new side plates and top plate extensions were cut, welded into place and the welds ground smooth. The resulting structure showed no signs of the change and was apparently designed as such originally

This, to the welding fabricator is nothing new—it is, in fact, "old stuff" It is merely included to serve as an example of the flexibility of the process in permitting design changes economically, even subsequent to fabrication. The designer need not be held down to having every part correct to the most minute detail before ordering any of the components

With particular reference to the dryer stands, it is questionable whether these parts could be produced by castings in the form that they are shown here; but even when redesigned to suit foundry practice, it is apparent that the patterns would be quite bulky and complicated, and would, in themselves, represent a considerable outlay. No two stands are alike, so that one could not serve for all.

If one frame or series of frames is made to serve for all, then the functional design of the machine must suffer.

It is also evident that a major design change after the casting is poured, involves scrapping the casting, altering the pattern and producing a new casting. It is as an old foundryman said when asked to make a change in a casting: "When you pour the mold, brother—there it is."

The only alternative in this case would be to cast a new bracket separately and bolt it in place. As well as being makeshift in appearance, this would involve alignment problems at assembly.

Creping Supports—Certain grades of paper must be creped, or removed from the first dryer by a scraping action. The dried film on the paper drum encounters a sharp blade which causes the paper fibers to crumble upon themselves, a sort of microscopic accordion action which breaks down the paper fibres and produces the soft textures of the tissues as differentiated from the hard finish papers. When it is considered that the paper film is

approximately one-fifth of the thickness of ordinary typewriter paper, it is apparent that the creping blade, or "doctor", must be mounted in very accurate alignment with respect to the dryer surface.

The doctor blade in itself is a thin sharpened strip of very hard bronze which is held against the dryer surface by a support which is pivoted axially at the ends so that the blade itself can be made to impinge against the dryer surface at the proper creping angle by rotating the support, as shown in Fig. 14. In this case, the reaction necessary for creping is furnished by a pneumatic cylinder which applies moment to the support through a lever.

It is the application of welding that concerns us primarily in the design of a proper support for this blade.

Ordinarily, a rolled angle iron is used for this purpose, and is apparently stiff and rigid enough to maintain blade alignment. However, there is a certain amount of mechanical vibration transmitted to the dryer from the driving mechanism. In the case of this machine, this effect has been minimized by the use of a chain drive; but in most applications, the drive is by spur gears, in which case the vibrational amplitude is more pronounced.

At any rate, the existing vibration is transmitted to the doctor support through the blade contact and bearings, and if the natural period of the support lies within the range of variable impulse rates as the machine speed is varied, a state of resonance may be reached that is highly injurious to the machine. It is possible in many cases to see the effects of this vibration in regular hills and valleys worn on the dryer surface by the doctor.

The effective method of combating this condition is to produce a doctor support with a high natural period so that it is entirely out of the range of driving mechanism impulse rates.

This is best done by using a stiff structure whose ratio of elastic modulus to weight is high. When it is considered that the nature of the loading is torsion as the blade is rotated up against the drum, the natural selection is a tube—or pipe for economical fabrication.

The pipe, or tube, should be steel, and should be as large as is possible within the space limitations and have a comparatively thin wall, since the

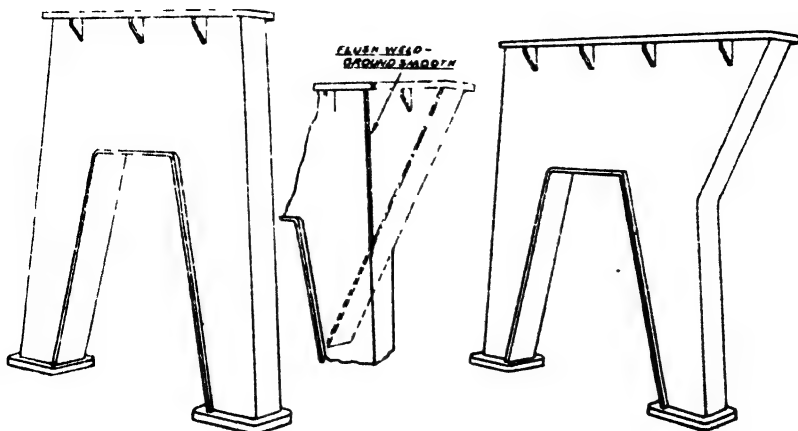



Fig. 13. Method of altering the stand.

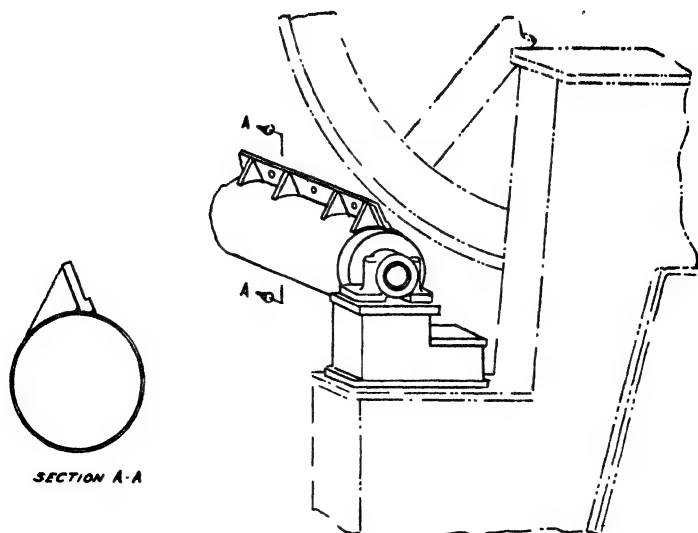



Fig. 14. Rotating support.

natural period is directly proportional to the square root of the moment of inertia and elastic modulus, and inversely as the square root of the weight.

The support and mounting is shown in Fig. 14.

Finishing Section—The calender frame, (See Fig. 15), is a variation of the press frame. Here, advantage is taken of the hollow section to incorporate the lever and pneumatic cylinder which loads the upper roll. This calender is small in comparison to most, but perfectly adequate for light weight papers.

The reel is a further adaptation of the standard section as is the slitter and rewinder. The unwind stand however, is an example of the economic use of the flat gas cut plate, the frame being a single plate set on two pads which serve as feet and bolting flanges. The bottom is scarfed out to permit mounting the roll bearings on the foot plate directly, and although these rolls are a part of the mechanism do not mount on the frame.

As the paper is unrolled from the reels, the diameter is reduced, and since the rolls of paper rest directly upon the fixed drums, the centers move constantly inward until the cores rest on the driving drums. This construction requires that the bearing housing slide in guides. Here guides were provided by machining gas cut slots in the plate frame.

A mental comparison can be drawn of the relative cost of this structure as built up of a single gas cut plate and two small rectangular pads—and the cost of producing similar castings where only two such units are required.

Cost Data—From the viewpoint of the welding fabricator, it would be useless to include our finished machine costs or that of the finished weldments. The average fabricator is interested only in how much it will cost his own shop to produce a certain structure.

Actual fabricating costs are completely misleading due to the different methods used by various companies in preparing cost data. One company may include materials and labor only in its shop costs, to which the management adds a sum representing a share of the annual overhead, engineering costs, etc. in order to arrive at the final sales figure. Another company may figure each item of its shop costs as containing its share of overhead, to which another sum containing engineering cost, profit, etc., must be added in order to reach its figure. There will be no comparison, therefore, in the cost sheets of the two representative systems under otherwise identical conditions.

In addition to which, the cost of labor differs widely from one section to another, and to a lesser extent, materials. These factors also tend to invalidate shop cost comparisons.

Therefore, in order that the fabricator may compute the cost of building a similar paper machine weldment by his own method, the subsequent data has been broken down into the most elementary components.

Because of the large number of parts involved, two frame pieces have been selected as representative—the couch roll support, Fig. 5, and the main dryer frame, Fig. 10.

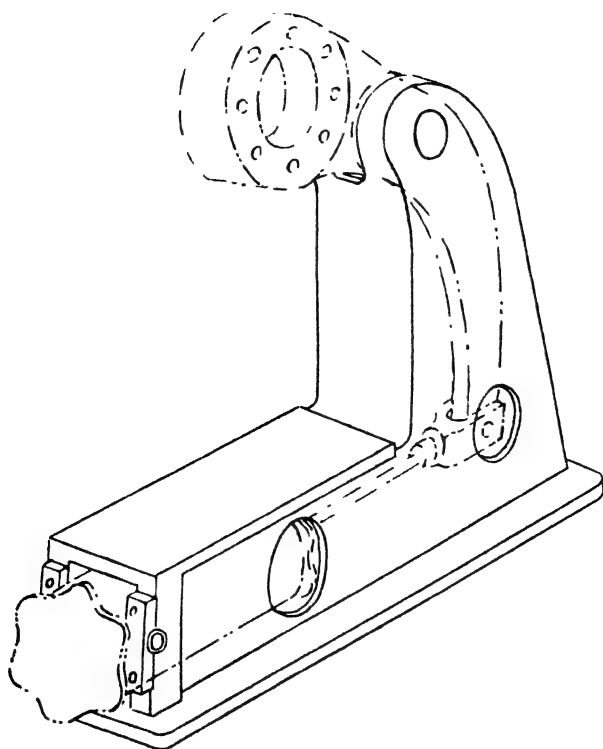



Fig. 15. Calendar frame.

Cost Computation Data for Couch Roll Support

I. Material

A. Universal Mill Plate — Pounds

4 pieces 12″ × ¾″ totaling 1,815# 1,815

B. ½″ Rectangular sheared plates

8 pcs. totaling 3,103# 3,103

C. ¾″ Rectangular sheared plates

6 pcs. totaling 263# 263

D. Gas cut plates (rectangular wts.)

5 pcs. totaling 778# 778

E. Bars—one 6 × ½ × 9¼

one 6 × ½ × 5¼

one 4½ × ½ × 19

one 6 × ¾ × 10¼ totaling 38

Total Gross Weight 5,997

II. Gas Cutting Required on Above Pieces

A. Cuts through Gauge

on ½″ plate	35′- 5″	total
on ¾″ plate	16′- 0″	total
on 1″ plate	9′-10″	total
on 1¼″ plate	32′- 5″	total

B. Gas Cut Bevels for Welding and Fitting

⅛″ × ⅜″	3′- 4″
⅜″ × ¼″	39′- 4″
⅜″ × 5/16″	2′- 8″
⅜″ × 7/16″	11′- 4″
½″ × ¼″	0′- 5″
½″ × 5/16″	4′-11″
½″ × ⅜″	1′- 0″
¾″ × ¼″	1′- 6″
¾″ × ⅜″	3′- 0″
¾″ × 7/16″	2′-10″
¾″ × ¾″	3′- 0″

III. **Bending.**

On 1 Universal plate (wt. 420#) 2 bends across 12″ width
On 1 Universal plate (wt. 405#) 1 bend across 12″ width
On 2 Sheared plates (wt. 110#) 1 bend in each 29″ long

IV. Assembly Data

In all, there were 35 pieces; net weight of all pieces—4,840#
Weight of individual large plates:

	Pounds
Side Plate	887
Bottom Plate	380
Bottom Throat Plate	405
Top Throat Plate	420
Top Plate	480
Back Plate	130
Rear Base Plate	316
Front Base Plate	86
Bent Outrigger Plates	110

V. Welding Data

Type	Length
¼″ 90 degree	1498″
⅜″ 60 degree	358″
⅜″ 90 degree	26″
½″ 60 degree	30″
¾″ 60 degree	62″
Gap Weld, open ⅜″ at bottom, through ¾″ plate	18″
¼″ 90 degree automatic machine weld	1336″

VI. Weight of Welding Rod Used—125#

Data for Cost Computation on Stand for Primary Dryer

I. Material

	Pounds
A. Universal Mill Plate 2 pcs. totaling 247#	247
B. ¼″ Rectangular sheared plates 1 pc. @ 36#	36
C. ½″ Rectangular sheared plate 2 pcs. totaling 2494#	2494
D. ¾″ Rectangular sheared plates 1 pc. @ 33#	33
E. Gas Cut Plates—rectangular weights 8 pcs. totaling 953#	953

F. Bars

	Pounds	
Six 2½ × ½	11	
Two 2½ × ½	4	
One 4 × ½	3	
One 6 × ¾	50	
One 6 × ¾	21	
One 6 × ¾	94	
One 6 × ½	60	
One 6 × ½	12	
	255	255
		4018

II. Gas Cutting Required on Above Plates

A. Cuts through gauge

on ½″ plate	96′-10″
on ¾″ plate	3′- 9″
on 1¼″ plate	34′-10″
on 1¾″ plate	4′- 4″
on 2¼″ plate	2′- 6″

B. Bevels for Welding and Fitting

¼″ × 5/16″	28′- 2″
⅜″ × ⅜″	1′- 0″
⅜″ × 7/16″	1′- 6″
⅜″ × ⅝″	0′-10″
½″ × 5/16″	12′- 0″
½″ × ⅝″	0′- 7″
¾″ × ¼″	1′- 4″
¾″ × 7/16″	0′-10″
¾″ × ⅞″	0′- 7″

III. Bending

On 1 Universal 8 × ¾" plate (wt. 204#) 2 bends—8" lg.
On 1 6 × ½" bar (wt. 30#) 1 bend 6" lg.
On 1 6 × ¾" bar (wt. 50#) 1 bend 6" lg.
On 1 6 × ¾" bar (wt. 21#) 1 bend 6" lg.

IV. Assembly Data

Total number pieces—40
Total net weight—2595#
Net weight of individual large plates:

	Pounds each
Side plates	580
Top plate	300
Middle bearing plate	130
Left hand Foot plate	160
Right hand Foot plate	65

V. Welding Data

Type	Length
¼" 60 degree	297"
¼" 90 degree	2698"
⅜" 60 degree	18"
½" 60 degree	19"
⅝" 60 degree	6"
¾" 60 degree	16"

VI. Weight of Welding Rod Used—105#

Cost Comparison of Weldments and Cast Iron Parts—As a general rule, no cost comparisons were made between castings and weldments, but the following situation that arose during the defense emergency may serve as a guide as to what should be generally true throughout the machine.

Subsequent to the installation of the machine, a decision was made to substitute a new unwinder with a lateral adjustment not originally incorporated in the machine. This change occurred during the height of the priorities "putsch" and doubt arose as to whether we could produce these parts ourselves because of a jammed shop; consequently we had inquiries sent out to local concerns to supply castings for the frame parts, in case the emergency arose. Combining the best rough casting prices and machining prices, we found that the total cost of the machined cast iron frame parts, including patterns, was $1,013 for the two sets of stands required. The total cost of the two sets of welded stands, completely machined, came to $571.30! In other words, the cost increase of cast frames was 77 per cent based on the cost of the welded frames. When it is considered that the cost of machining—approximately $233—safely assumed to be the same in both cases, is removed from both, the percentage of saving becomes even more apparent.

In this case the rough castings cost $780 including patterns, and the rough weldments $338.40. The difference (or saving) $441.60 represents an increase of 130 per cent over the weldment cost.

It should be stated here that the cost comparison is valid, in that our weldment figures include overhead, burden percentages, salesman's percentage and our usual percentage of profit, in addition to actual shop costs, together with an outside machining price.

I admit freely, to be fair, that such high percentages of savings are not always possible. In this instance, six separate patterns were required that were none too simple, and it was possible in the welded design to use a number of parts cut from bar stock incorporating a minimum of gas cut plates. On the other hand, this was done at no sacrifice in appearance; the welded structure has the same external appearance as the cast would have had, even to smooth welding fillets used where the pattern maker would provide radii in the corners; and the use of bars or other rolled shapes is certainly the welding designer's prerogative.

Conclusion—Welded steel is particularly suited to the paper machine for the following principal reasons:

1. Its high strength to weight ratio makes possible the design of lighter and stronger framing than previous practice. Members designed for a minimum of deflection can be more easily attained with less material by the welded steel process.

2. Machine elements can be made in one piece by the welded process, hitherto impossible in castings.

3. Greater efficiencies and space economies can be obtained by the greater heat transfer properties of the thinner but stronger steel dryer shells.

4. It is possible to obtain a better finish on the steel dryer than possible on cast iron, and therefore a better finish on the paper.

5. In units designed for high natural vibration periods, there is an advantage in the higher elastic modulus-weight property of steel.

6. Advantage can be taken of the fact that changes can be made to welded steel during and subsequent to manufacture in order to effect economies of time, material and expenditure.

7. Paper machines are largely a "one-shot" product—it is a rare occurrence when two are built alike. Welded steel, then, eliminates the expenditure for patterns that must be absorbed in the cost of one or two castings.

All in all, the paper machinery field is a relatively dark continent, inviting exploration and missionary work of the welding fabricator.

Chapter XXI—Welding Jaw Crusher Bases

By Ralph W. Heer and William A. Eckley,

Assistant Chief Engineer and Designer, respectively, Pioneer Engineering Works, Inc., Minneapolis, Minnesota

Ralph W. Heer

Subject Matter: The multiple advantages gained by welding jaw crusher bases. Since the function of the machine is to crush rocks by jaw action, it is necessary to have great strength in the base. Older designs were of ribbed cast design. The added strength of box design was observed, found difficult for casting but was used in the welded base. The result was a stronger, lighter, and better-looking base. Experience in welding technique resulted in the reduction of $104 from the cost of the first unit ($399). A table showing both the actual and percentage savings in weight and cost of the complete line of machines is included. Weight savings range from 15% to 30% without loss in strength and cost savings ranged from 11% to 35%.

William A. Eckley

Multiple Advantages Gained by Welding Jaw Crusher Bases—The jaw crusher, (See Fig. 1), is a machine used to reduce rocks and ore by mechanical means. Essentially, it consists of a pitman, shown in Fig. 2, which is hung on an overhead eccentric shaft in a box-shaped crusher base. A circular motion is imparted to the upper end of the pitman by rotating the eccentric shaft, which in turn is converted to an oscillating forward and backward motion on the lower end of the pitman by the toggle plate. The toggle plate controls the length and direction of the motion of the pitman toward the base and the width of the opening between the pitman and the base by adjusting the toggle seat in the base relative to the toggle bearing seat in the pitman. Also, adjustment is made by changing the length of the toggle. On the side of the pitman, facing the open end of the base, and on the inside of the base facing the pitman, between which the rock crushing is done, are replaceable crusher jaws which are usually made of manganese steel. Other main parts of the crusher are the tension rod and spring which hold the pitman against the toggle plate, the adjusting mechanism, and the flywheels which store energy to transmit to the eccentric shaft during the crushing stroke.

In actual operation, rocks are fed between the jaws of the pitman and the base. The eccentric shaft rotates, causing the pitman first to open away from the base, forcing the rocks deeper into the crusher by a combination of crowding action and gravity peculiar to this type crusher. Further turning of the eccentric shaft moves the pitman against the rocks with such force that they are crushed. On the next opening of the crusher, the crushed rock falls down on through the crusher jaws and larger rocks from the

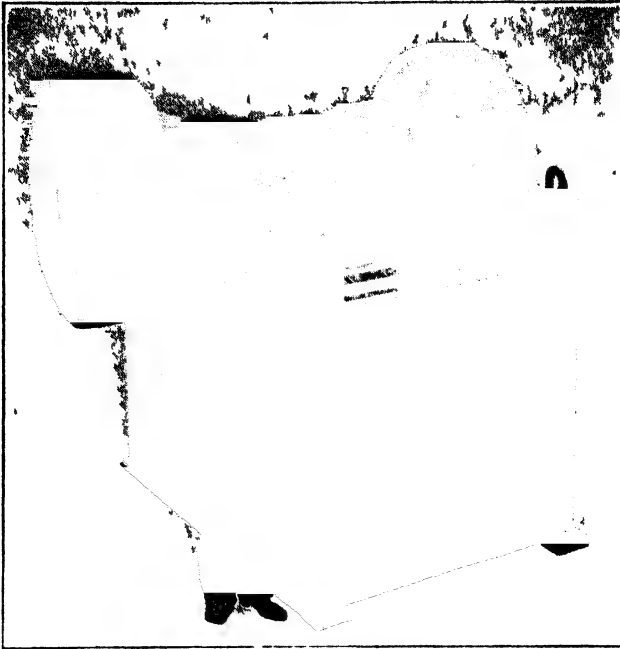



Fig. 1. Welded base.

top replace them. This cycle of operation occurs at about 250 revolutions per minute for most anti-friction bearing jaw crushers. The upper section between the pitman and the base does the crushing of the large rocks directly from the eccentric shaft motion, while the enormous forces required to crush the smaller rocks are obtained at the bottom by the toggle action of this crusher.

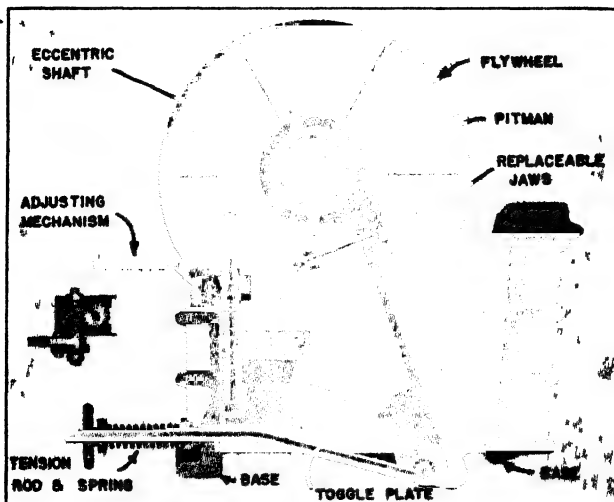



Fig. 2. Pitman.

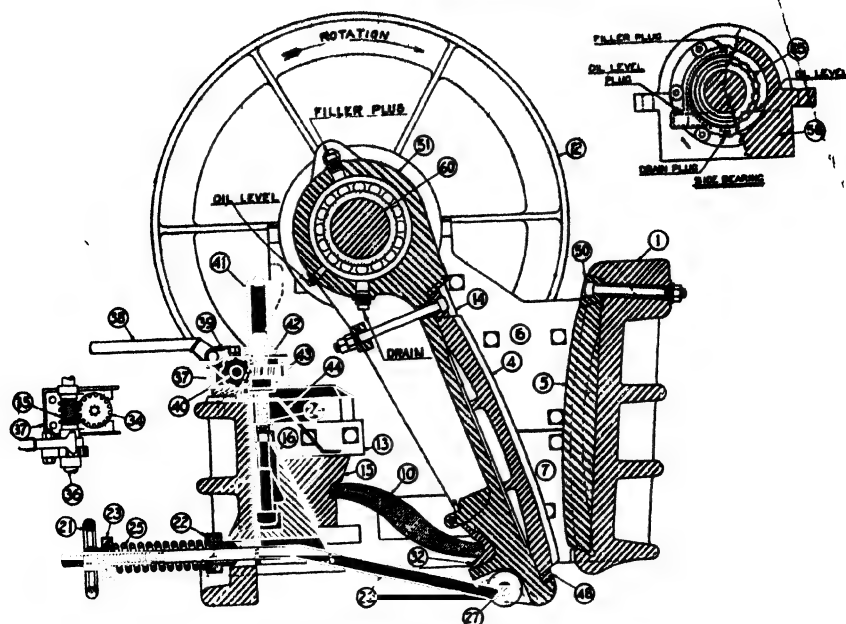



Fig. 3. Cross-section cast base jaw crusher.

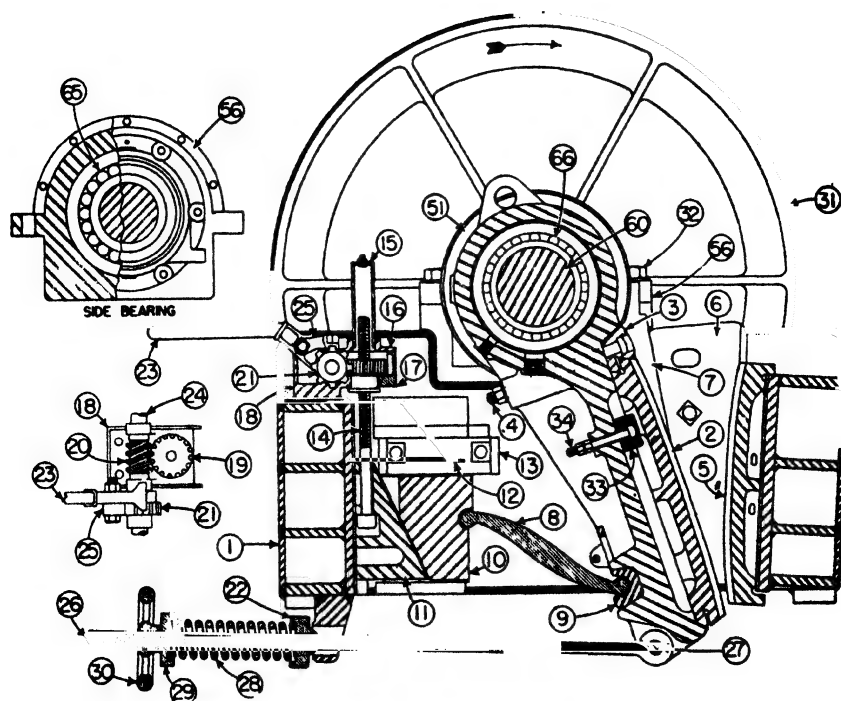



Fig. 4. Cross-section welded base jaw crusher.

From inspection of the above operation, it can be seen that both ends of the crusher base must be able to stand the forces of crushing the rock in beam action with repeated loading while the sides of the base which hold the outer eccentric shaft bearings must withstand plain tension, with repeated loading, horizontally, and reversible tension and compression vertically. There may also be a bending in the sides if the ends of the base deflect too much, in which case, the sides breathe. The corner sections as well as all other sections must stand large shearing stresses which are in most cases caused by repeated loading, but which in some cases pass through a complete reversal of loading. With these stresses in mind, the authors bring the evolution of the jaw crusher base from its original cast design to its present modern welded design.

For a number of years, jaw crushers were built with an inner wall reenforced by horizontal ribs running completely around the base. These ribs were stiffened by vertical ribs. A typical cross section using this construction is shown in Fig. 3. However, this type of construction is not as strong as a box section, Fig. 4, of equivalent weight, so in 1938, the possibility of building a box section cast base was investigated. It was found possible to reduce the weight quite materially and still maintain the same strength of base. The appearance was also greatly improved because of the smooth outer walls. This proposed base is shown in Fig. 5. With thin inner and outer walls, the accurate alignment of cores is absolutely essential, but difficult to attain in practice. Removal of cores presented another difficulty. Because of these difficulties involved in coring, the idea was deemed not practical and dropped.

In November, 1939, the box section crusher base was again considered, but this time with built up welded construction. A crusher base was built in the 10 inch x 24 inch size in January 1940, and is shown in Fig. 6. This

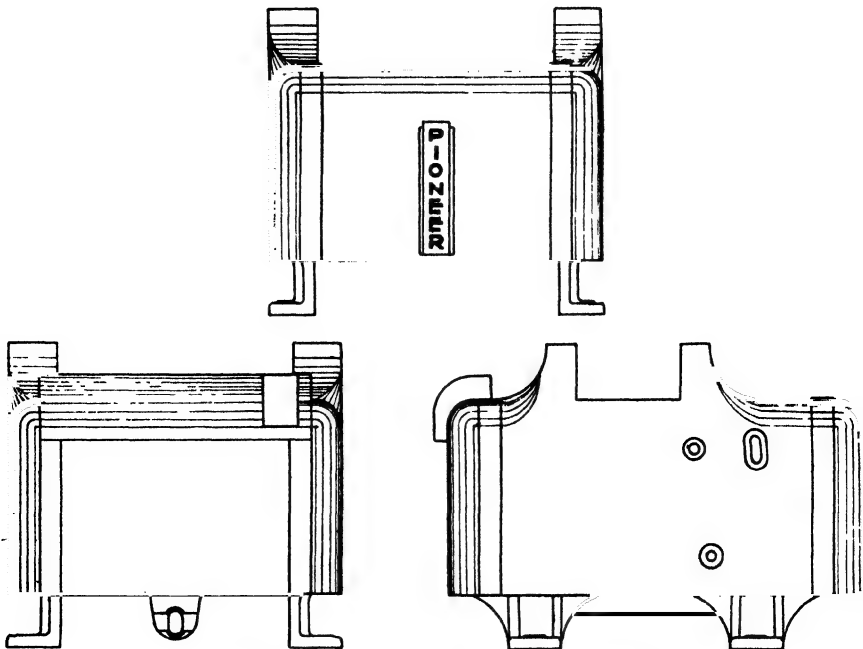



Fig. 5. Proposed design of cast steel base.

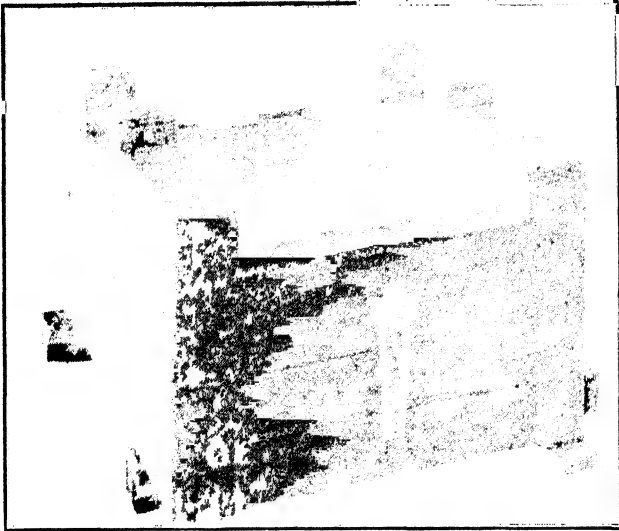



Fig. 6. Front view of first welded base.

crusher was built in the following manner each of the 4 sides had its horizontal and vertical ribs welded in place The two side plates each had a bearing housing support casting welded in place This casting is shown in Fig. 7. The four sides were then assembled and welded together The outer plates were then welded around the entire base On the first crusher base, three outer plates for each side were used to facilitate welding to the inner ribs Later, single, full sized plates were used with punched holes in rows lining up with the inner ribs The ribs could then be plug welded to the outer plates with considerable saving in welding time and material This type of construction has proven to be very satisfactory, and the entire line of jaw crushers from the smallest to the largest were redesigned for box section welded bases.

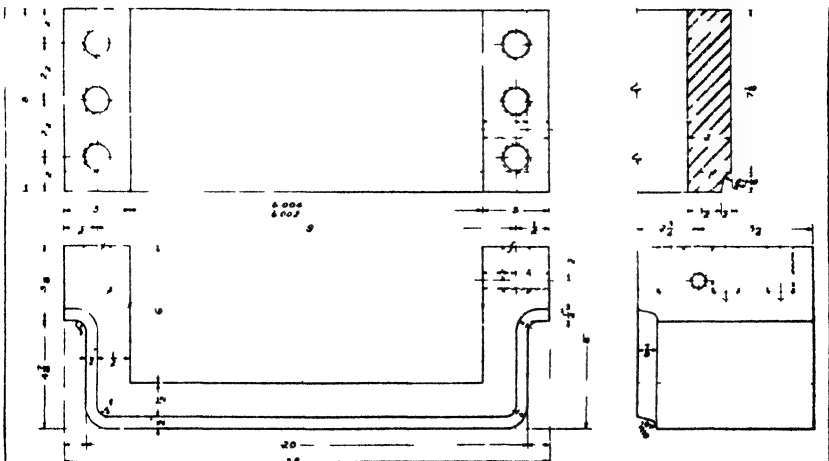



Fig. 7. Bearing housing support casting.

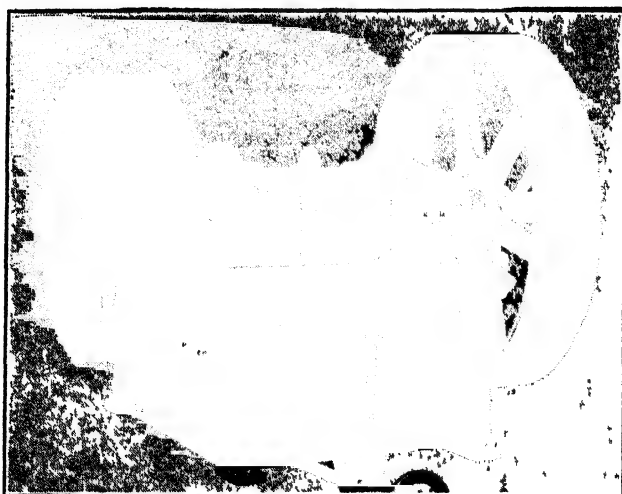



Fig. 8. Rear view of first welded base.

In order to show the advantages resulting from a welded box section base, the two following examples may be cited.

Calculations for the section modulus of the end against which the stationary jaw bears have been made for the 24-inch x 36-inch cast base, 24-inch x 36-inch welded base, 9-inch x 18-inch cast base, and the 9-inch x 18-inch welded base. The comparison is as follows:

918 Crusher.

Type	Section Modulus	Weight Ratio	Sect. Modulus Ratio
Cast Base	39.1	100%	100%
Welded Base	32.0	41%	82%

2436 Crusher.

Type	Section Modulus	Weight Ratio	Sect. Modulus Ratio
Cast Base	163.	100%	100%
Welded Base	359.	71%	200%

The box section used on the 24-inch x 36-inch crusher increased the section modulus 120% with a 29% decrease in weight for this part of the crusher base. On the 9-inch x 18-inch crusher, the section modulus was decreased 18%, but the weight was reduced 59%. In this case, the cast base was considered to be stronger than necessary.

The cost of the first welded base crusher built was $399 or $104 higher than the present cost for a 10-inch x 24-inch welded base crusher, (Fig. 8). Inexperience, warping due to excessive concentrated strips of welding, extra labor, and material costs for excessive welding, stress annealing and sand blasting contributed to high costs on the first welded base. Plug welding of outer plates, shown in Fig. 9, to inside ribs and reduction of size of weld between ribs and inner plates eliminated most of the warpage and reduced material and labor costs. Since the first machine, no bases have been annealed for stress relief or sand blasted.

A tabulation has been made to show comparative weight and cost figures for the cast and welded base crusher now being made. Since the 30-inch x 42-inch welded base, Figs. 10 and 11, is a new size, no comparison can be made. The 24-inch x 36-inch welded base has been designed but never built, so no costs are available.

Comparative Weight and Cost—Cast and Welded Jaw Crusher Base.

Number	Description	Weight	Total Cost	Material Cost	Welding and Machine Labor Cost	Set-up and Welding Time	Pattern or Jig Cost	Per cent Weight Saving	Per cent Cost Saving
9" x 18"	Cast base	2,405	$307.53	$250 54	$21.92		$650		
9" x 18"	Welded base	1,350	198.19	70.12	52.00			44%	35%
9" x 24"	Cast base	2,558	301.50	250.76	19.58		700		
10" x 24"	Welded base	1,963	263 00	94.99	70.65			23%	13%
10" x 36"	Cast base	3,995	513.33	403.67	42.20		800		
10" x 36"	Welded base	3,060	355.88	130.51	90.86	66.6 hrs.		24%	30%
15" x 24"	Cast base	6,393	695.41	604.78	34.86		100		
15" x 24"	Welded base	4,150	457.67	173.21	115.57			35%	34%
15" x 36"	Cast base	7,582	907.13	806.34	40.69		1,200		
15" x 36"	Welded base	5,445	811.49	246.86	229.10			28%	11%
24" x 36"	Cast base	12,183	1,503.10	1,290.36	81.83		1,500		
24" x 36"	Welded base	10,150 (Est.)						16.5%	
30" x 42"	Welded base	14,417	1,465.26	658.04	328.05	215.0 hrs.			

*Direct saving made during the first fiscal year that welded crusher bases were made from October 1, 1940 to September 30, 1941 amounted to $2,625. This figure is low because we had not made a complete changeover to welded bases. A complete changeover based on the same number of sales would have given us a saving of about $17,000. One order we now have for ten 30-inch X 42-inch crushers welding will save in direct costs about $7,600.

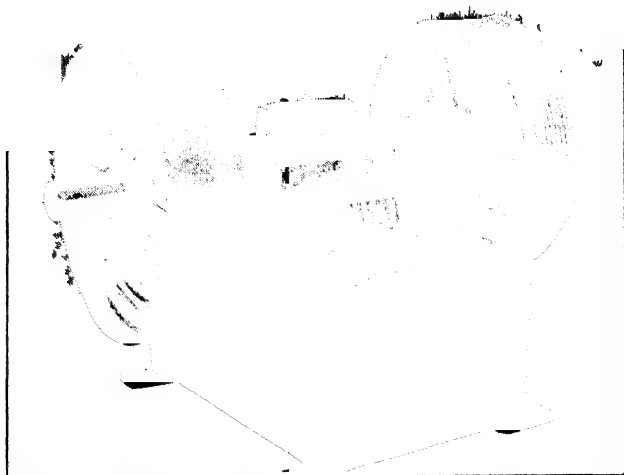



Fig. 9. Front and side view of 10 x 16 welded base.

It is apparent from the preceding table that certain very definite advantages are obtained with a welded crusher base of box section construction. Weight can be cut 15% to 30% with no decrease in strength. This is a decided advantage in the building of portable rock crushing machinery. With the tendency for building larger and heavier plants to increase production of crushed rock and gravel on the one hand, and more drastic limitations on highway loading on the other hand, weight reduction with no sacrifice in performance becomes imperative Weight reduction is of the greatest practical importance both in reducing the cost of the crusher itself, and also in reducing the cost of the truck upon which it is mounted, by using lighter frames, axles, tires, etc

Since the 30-inch x 42-inch welded base crusher is a new size, no direct comparison can be made However, by making a comparison with the 24-inch x 36-inch cast base crusher, some idea of the weight and cost savings may be derived. The 30-inch x 42-inch crusher is capable of doing 50% more crushing per hour than the 24-inch x 36-inch crusher, but the 30-inch x 42-inch welded base weighs only 2235 pounds more than the 24-inch x 36-inch cast base, or an increase in weight of 18%. The cost of the 30-inch x 42-inch welded base is $38 cheaper than the 24-inch x 36-inch cast base, or a saving in cost of $2\frac{1}{2}$%.

Greater economies in cost undoubtedly could be made by using welding jigs in fabricating these welded bases With so many different sizes of crusher bases, and only small production for any one size, welding jigs do not seem to be necessary at this time. Jigs for positioning have been made to take all sizes and these have been responsible for saving time as well as producing better welds.

By the use of welding, a much neater looking crusher is possible, a comparison of which is shown in Fig. 12. Walls of uniform thickness of homogeneous material are attained only by welding steel plates together. Former sloppy appearance caused by blow holes, core shifting and rough surfaces is no longer present in welded construction. A much better paint job is possible on welded steel plates than on rough steel castings. This design

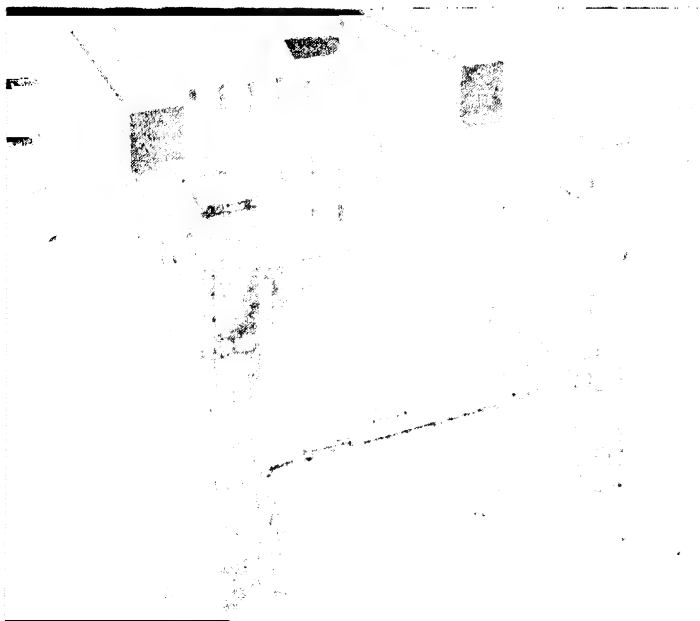



Fig. 10. Rear view of 30 x 42 welded base.

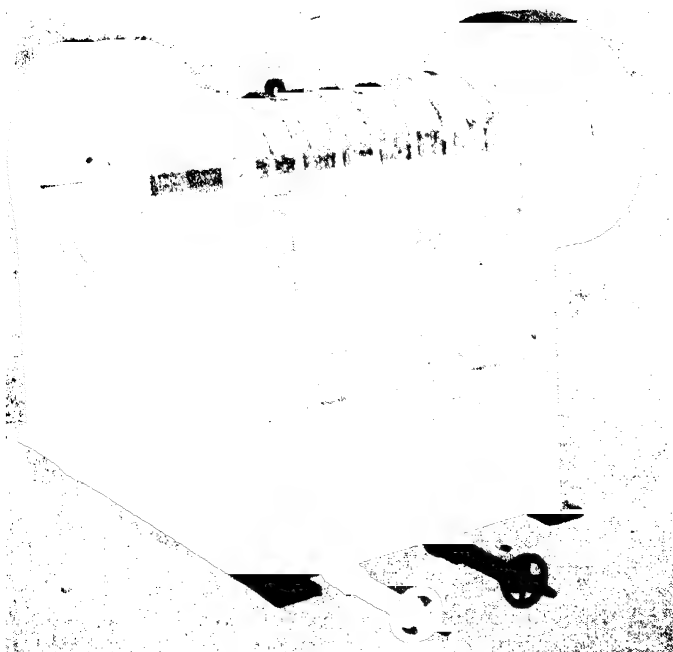



Fig. 11. Rear view of 30 x 42 welded base crusher.

Fig. 12. Comparison of first welded crusher base with cast base.

meets the present day demand for smoother outward appearance, coupled with simplicity. (Compare Figs. 13 and 14).

Another saving is the elimination of pattern costs which vary from $650 to $2500. Modification of design after the pattern has been made, with resulting pattern changes further add to the cost. Time is lost in the time required for making the patterns and also when changes in the pattern must be made. Patterns must be kept in repair or poor castings will result.

The break down of our labor costs tabulations which contained the cost of structural welding and machining could not readily be obtained. It was found from machine shop records that the saving in machining time was from 20% to 25%. This saving results from the fact that welded structures do not include the hard slag, sand, and chilled spots found in steel castings. The sand and slag inclusions are especially bothersome because they increase the tool grinding time, decrease the tool life, and in many cases, make it necessary to spend as high as four hours on a base casting chipping out sand and scale inclusions before machining can be accomplished. The fact that cast bases require many intricate cores which often are not set properly by the foundry,

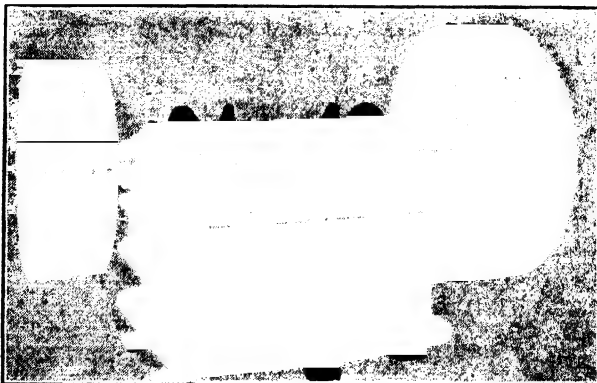



Fig. 13. Former cast base crusher. Note rough appearance.

or because the cores shift during the pouring, also add a difficult problem to machining a cast base. The shifting sometimes steals the material on one side, leaving too little stock for machining while on the other side, the amount of stock which has to be removed is more than is economically practical. Further difficulties encountered in the cast steel base not found in the welded base are the appearance of blow holes which must be welded up during machining operations. Also, glass hard chill spots which break down the cutting edge of the tool must be chipped out. Foundry sand and grit falling off the casting on to the ways and working parts of the planer cause premature wear of the machine.

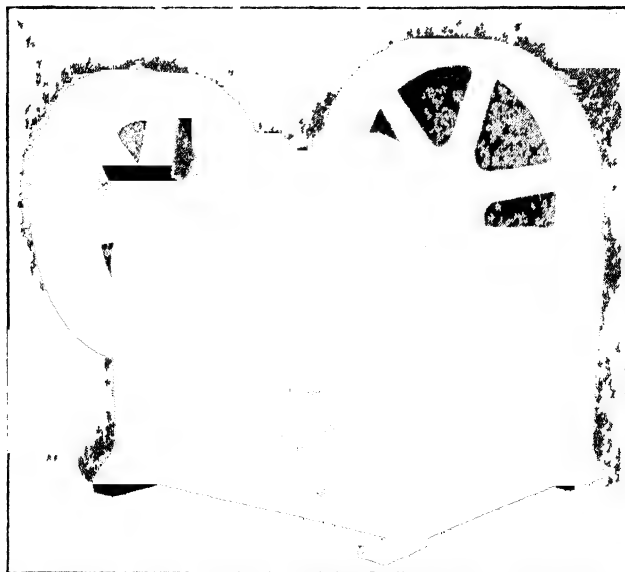



Fig. 14. Side and front view showing possibilities of styling with welded construction.

Up to the present, we have been more or less comparing only the relative merits and costs of the cast base and welded base. However, in producing the welded base jaw crusher, we found many production advantages that added to the initial savings made in the new design. One noticeable advantage was that holes which previously were cored and very often were not accurately located came where they were intended in the welded base, cutting down the fitting time during assembly. The sides of the welded base were smoother and came more symmetrical which reduced the amount of shimming in locating the removable jaws.

In looking back on the development of the box section welded steel base, it will be noticed that it has taken place in a relatively short space of time. The first base was built in January, 1940, and put through its paces for six months of actual operation in the field to show up any weaknesses that might develop. Proving satisfactory in every respect, it was decided to redesign the 10-inch x 36-inch base for welded construction. This crusher also proved to be satisfactory so all sizes of cast bases were redesigned for welding and a new larger crusher, the 30-inch x 42-inch, was given a welded base.

In this paper, we have stressed the advantages of the box sections in the welded base crushers very much because we believe that welding gave the only practical means of using this design. In the past our competitors have made welded base jaw crushers, but in all cases brought to our attention, they merely copied the old T section design of the cast base, substituting steel plate and welded metal for the casting. This design, we believe, is better than the cast base, but does not take full advantage of the welding possibilities.

Reduction of weight, decreased cost of manufacture, and all the other advantages mentioned before, have brought the welded base into actuality. The increasing number of satisfied customers is proving the superiority of welding for the fabrication of crusher bases.

Chapter XXII—Arc Welding Applied to Waxing Machine

By Joe Baxter, Jr.
Sales Engineer, Shartle Brothers Machine Co., Middletown, Ohio

Joe Baxter, Jr

Subject Matter: Arc welding as a development tool applied to paper-waxing machine. The history of reasons for turning to arc welding is given first. The design was stimulated by a customer who wanted a "prettier" and "faster" machine. The streamlined model appeared in 10 weeks as a result of arc welded construction. Cast iron construction and arc weld construction are compared as to (1), man-hours; (2), material costs (approximately 29% more for cast iron construction); (3), time for delivery (16 weeks for cast iron, 10 weeks for arc welding). Speed of paper through machine increased from the usual 700-feet per minute to from 900- to 1,200-feet per minute. Author emphasizes arc welding as a development tool.

"Arc welding as a development tool" was chosen as part of the title of this paper for one very outstanding reason. It proved to be the one means by which we could capture the enthusiasm of a customer and translate it into a functioning unit in the brief span of ten weeks. The lessons learned in doing so may well prove the salvation of any manufacturer who finds that they occupy much the same position we did in March, 1940.

Established at the turn of the century, our company had invested in ample foundry equipment to meet the requirements of a line of cast iron products. As new products were added to the line, the foundry was always foremost in consideration, with the result, that when welding finally broke into our shop, it did so hindered by this statement, "Use it for new stuff, where only one unit is required, but where several units are indicated over a period of a year or two, make patterns".

Inasmuch as ours was a "specialty" shop in a sense, our welding department continued to expand, based on new stuff only. There was no conscious effort to redesign the old line of equipment to welded construction. That is,

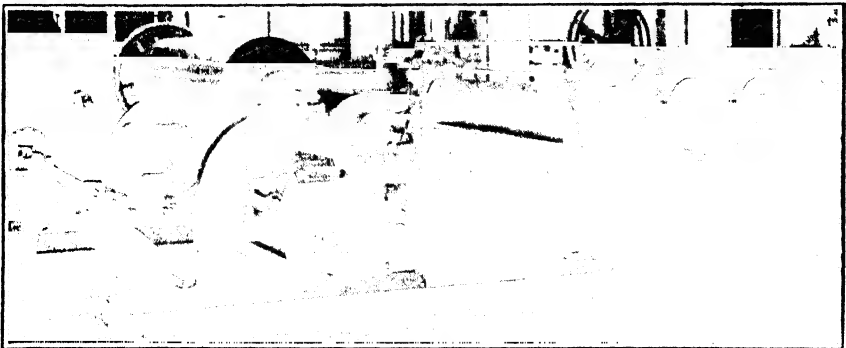



Fig. 1. Front view of waxing machine.

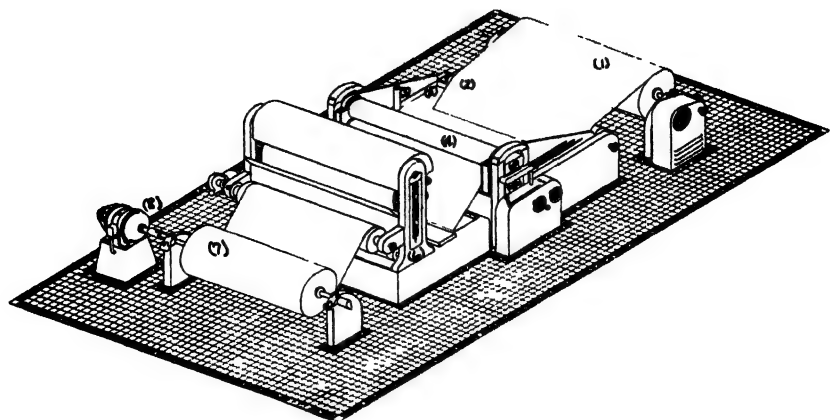



Fig. 2. Free-hand sketch of new waxing machine.

until we received a phone call from one of our customers. "Have your representative call in regard to a waxing machine."

In 1936, we had purchased the good-will and equipment of a small concern whose main item had been a waxing machine. And, from 1936 to March, 1940, we had sold exactly two machines from those patterns. The renovating of the patterns to a usable condition, and sales' overhead involved, showed a nice loss and as a consequence, we were not overly enthused when the phone call informed us of a potential customer.

"I want the best looking waxing machine on the market," was our customer's greeting. That's easy, we thought, as we laid photo, Fig. 1, in front of him. And, we weren't kidding ourselves at all. It was the best looking waxing machine on the market—at that time!

"Listen," he said, "I make wax paper for bakers. They insist on cleanliness in the bakery business. I want a machine that'll be prettier than any bakery equipment in the country—that I can bring a baker into my plant and say, 'see how I make my paper!' And I want that machine to be more efficient, and run faster than a wax machine has ever run before."

"How fast?" we asked.

"1000 feet per minute, 72-inches wide."

We had our specifications. Overnight, we made a free-hand sketch of such a "dream" machine, (See drawing, Fig. 2), figured the cost, and laid both before him the next day, with a somewhat apologetic attitude and the stipulation that "In order to meet delivery, we must weld it." (Then too, only one machine was involved).

"OK, go ahead."

A 12-hour ride returning on the train, gave us sufficient time to sketch each detail, so that engineering could be started at once.

Ten weeks later, we took photo, Fig. 3—from approximately the same angle we had drawn the original sketch. "Open house", brought wax paper manufacturers who were not at all reticent in expressing their approval, and within six weeks $54,000 in sales further attested to the changes made. Furthermore, a nominal profit had been realized, and we were all set to produce arc welded waxers by-the-dozen when the foundry again made itself known.

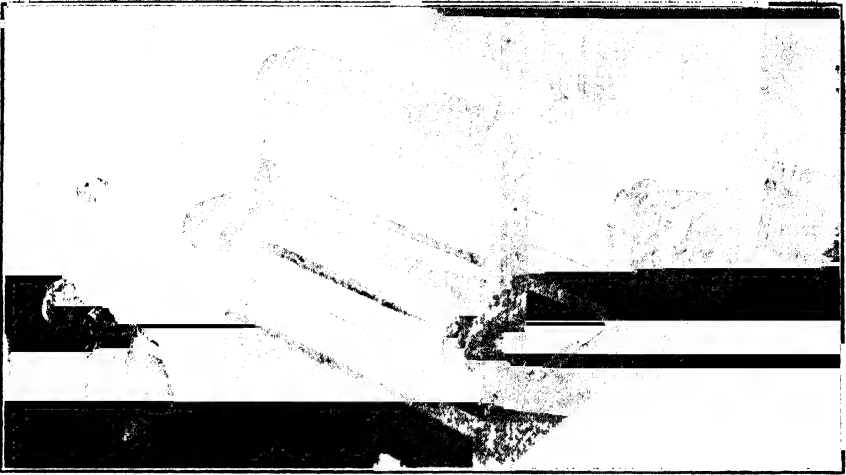



Fig. 3. Overhead view.

So our welded machine was dissected to give balance to the shop, and foundry. Patterns were made, precedent was satisfied, and a loss sustained.

By this simple return to cast-iron construction, we had a chance to actually evaluate "welded vs. cast-iron" construction in terms of cost, appearance, and time required to complete. A brief study of comparative design and cost will definitely show the value of "arc welding as a development tool".

Arc welding allowed us full expression by being able to cast aside any inhibitions or restrictions ordinarily imposed by the use of cast-iron.

Consequently, a layout of operating component parts was made without regard to methods of construction, but with emphasis on convenience and operating efficiency. Around this layout, arc welding principles were applied to give supporting structure and to position operating units in proper relation to each other.

The waxing machine shown on drawing, Fig. 2, reading from upper right corner to lower left corner, consists of:

(1) Unwind stand, on which roll of paper to be waxed is placed.

(2) Guide roll, over which sheet passes for alignment in machine.

(3) Dip roll, adjusted vertically for submerging sheet for required dwell in wax.

(4) Squeeze roll section, consisting of bottom chilled iron roll, and rubber covered top roll, micromatically adjusted for determining quantity of wax to be applied.

(5) Steam jacketed wax pan for melting and containing the molten wax.

(6) A water finish attachment for chilling the molten wax quickly by means of refrigerated water, and then removing small adherent beads of moisture.

(7) Rewind stand, for reeling waxed paper back into roll form for further handling.

(8) Drive, for synchronizing respective parts with each other and applying motive power.

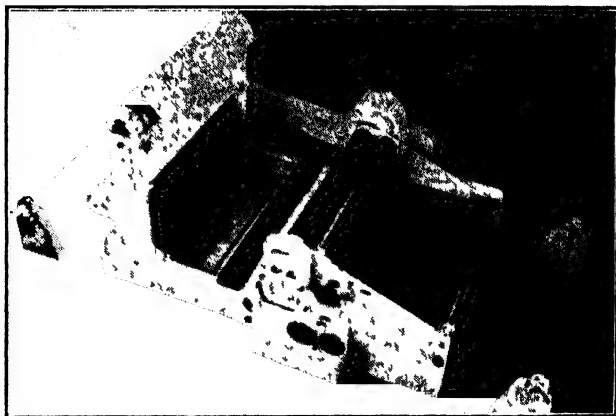



Fig. 4. Another view from above.

Each part can be clearly seen in photo, Fig. 4. Photo, Fig. 5 is a closeup of the unwind stand. A frictional brake is built into the housing at the left for maintaining proper tension in the sheet. Note that the stands are welded, with separate closure strip to complete the box section after stands are bolted to the floor. The stands were contour-sawed, corners formed on a 'brake', with a single weld down each edge.

The friction band was of welded construction and controlled by handwheels as shown. The grill expels heated air thru the friction pulley, while cool air is admitted from floor level thru louvres. The stands were of 3/8-inch steel, the housing of 1/4-inch steel.

The main frames, (See Photo, Fig. 6) were contour-sawed from 3/8-inch plate with corners broken by bending press. Where corners met, welding rod was filled in to build up contour. This produced a hollow frame with ample cavity to accommodate counterweight for dip roll. Counterweight was welded to a piece of oil chain passing over a roller sheave housed in locking bracket.

The two side frames were spaced by means of cross-ties made of 6-inch H-beam having a steel plate at the ends which were turned to form male centering bosses that mated with drilled holes in the side frames. This construction gave extreme rigidity, and provided a means of anchoring to floor with no anchor bolts showing when installed. These same cross-ties supported the wax pan. Thru this construction it is no longer necessary to dismantle the machine for shipment.

Styling was in harmony with the straight lines of the welded construction. All levers terminated in plastic balls, and handwheels were of plate design, resulting in a clean cut design, whose theme was paced by the neat lines of the welded construction. To conceal actual mechanism of top roll adjustment, boxed closures of 1/8-inch steel were contour-sawed and welded.

The wax tank was formed on brake, and fitted with labyrinth steam chamber. Over this structure, magnesia insulation was applied and encased permanently with 1/16-inch steel cover welded in place. This was, to our knowledge, the first such wax tank insulated as a part of its initial fabrication.

The water finish attachment was similarly constructed. Here welded plates

gave classic lines. The snap-cover on front and back had a plastic ball handle on welded stud, and being made of $1/8$-inch sheet steel, they had spring steel clips welded to them without being apparent on the exterior surface.

The space between wax pan and the water finish tank was closed by welded sheet steel closures. Valves for control of incoming water were thus conveniently located and protected. On old machines, this space is a messy collection of broken paper and spilled wax.

There are four exit pipes for the warm water on the left wall of the tank. These are piped together and completely skirted with welded steel cover.

Splash cover overhead is galvanized steel welded to pipe fittings for returning water thrown off by centrifugal force as paper passes over top roll.

The rewind stands were constructed similarly to the unwind stands.

The drives were completely enclosed with welded steel housings, thus insuring safety to the operators.

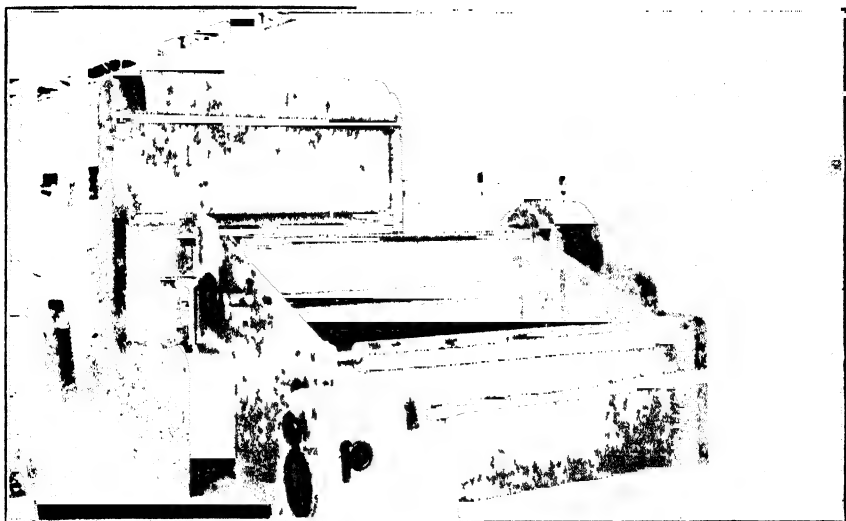



Fig. 5. Waxing machine from unwind end.

From the photos it is quite apparent that appearance has been definitely stepped up—that redistribution of weight has resulted in greater rigidity, with the result, that where 700-feet per minute was considered tops for a cast-iron machine, the welded machine has run experimentally at 1500-feet per minute and operates consistently at speeds of 900- to 1200-feet per minute, depending upon the grades of paper being run.

Had it not been for the foundry, the complete machine would have continued to be made of arc welded construction. However to meet this demand, the unwind and rewind stands, the frames of waxer and water finish attachment, and the caps over the bearing slides on the waxer, were made of cast iron.

The patterns so involved, required $400 worth of materials and 825 man-hours, plus a six-week delay for castings to come from foundry.

These are actually the records of two similar machines with the cast iron substitutions above mentioned.

Manhours

Arc welded construction	2150
Cast-iron construction	2143
	7 manhours saved by cast iron.

Material Costs

Cast-iron construction	$4340.62
Arc welded construction	3844.89
	495.73
Plus 1/5 pattern cost	550 00
	1045.73 material cost saved by arc welding

Elapsed Time from Order Received to Delivery

Cast-iron construction	16 weeks
Arc welded construction	10 weeks
	6

The above is a competitive comparison, and does not take into consideration the loss of one frame through inaccurate drilling, that could not be salvaged as could a steel frame by plugging holes with weld metal and redrilling.

Hence material cost was approximately 29 per cent more in cast-iron construction, and hours about balanced out.

The lessons learned from the waxing machine are now being applied to other products of our manufacture. Having used arc welding as a development tool and found it not wanting, we no longer fear the new, but design

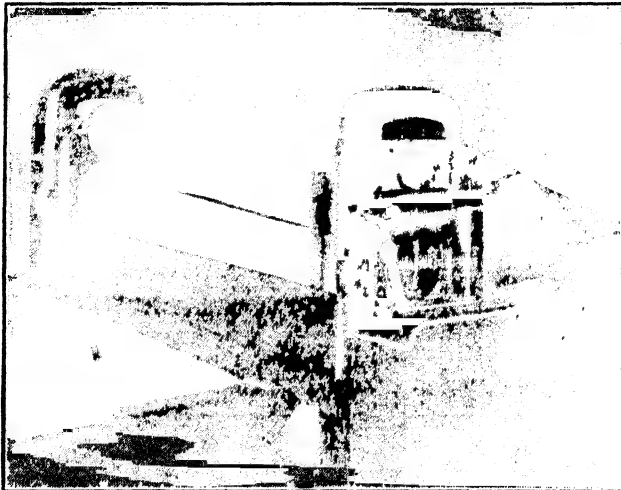



Fig. 8. Detail of controls.

boldly for the need at hand, then apply arc welded construction, of the right proportions, eliminating as many machining operations as possible. Thus we get massive clean cut proportions, with a minimum of curves and angular lines.

We have demonstrated to our own satisfaction that when arc welding is used as a development tool, it is possible to retire the first cost, and—at a profit.

So much of the value of such a project is intangible. In our case, we immediately realized sales 200 per cent of normal. We gained prestige throughout the trade conservatively estimated at $500,000, since the success of our first machine reflected favorably on other items in our line. We gained confidence in our ability to cope with those customers who want something "a little bit special".

The waxing machine market as such, is a relatively small one, with ten machines per year distributed to all manufacturers being the maximum, so from a strictly monetary point of view the redesign of this machine was of relatively little importance. But aside from its monetary value to the machine builder, the redesign is important to the purchaser, since he can, through its use, produce from 30 to 50 per cent more paper at practically the same initial cost as formerly. Being of steel construction his maintenance and replacement cost over a period of years will be less and wax papers to bakers will naturally reflect the lowered cost of production, with the result that the effects of the redesign of this machine will appear on the breakfast table of 130,000,000 well fed Americans. Waxed paper not only protects their food, but enhances its appearance. If a loaf of bread looks good, the chances are—it will taste good too!

Chapter XXIII—Tractor Transmission Case and Frame Assembly

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Subject Matter: The design, construction, features and cost of making an arc welded wheel-type tractor transmission case and frame assembly. The use of arc welding made possible a wheel-type tractor which had good power, speed maneuverability, ground bearing, ruggedness, load carrying capacity, and low initial and maintenance cost. The design allows 40 per cent of the load weight and part of the drawn units weight to be on the driving wheels. Low-alloy high-strength steel assembled by arc welding resulted in a large decrease in weight and 50% decrease in cost as compared to similar cast steel design. Construction details include control of weld sizes, costs, and correct materials.

The story of man's rise from primitive savagery is primarily one of his development and use of better tools. The amount of physical energy which modern man can spend each day in solving his problems of living is probably little different than his primitive ancestors had. The improvement in the way of living of modern man over that of his primitive ancestors is primarily a difference in the tools which he uses to multiply the energy he uses each day.

From time to time in his rise from savagery, man has developed a new tool or process which embodies some inherent economy of his energy, and of the materials available for his use. Occasionally a new tool or process involves such great savings of labor and material that in a comparatively short time, large parts of the then existing industry are considerably changed.

Such a tool is arc welding.

The arc welding process was originally experimented with by mechanics and engineers as a repair and maintenance tool. Very early in its use the inherent economies in the use of material and labor, together with the advantages of strength, function, and freedom of design compelled the most progressive mechanics and designers to use this new tool in the manufacture of the machines and equipment for the needs of modern society.

There are two important steps in the realization of the full measure of economy made possible by the development and use of the new tool—arc welding. The first of these is either the redesign of some already existing machine or piece of equipment using arc welding to replace some conventional method of manufacturing the same equipment, or the designing of a related piece of machinery or equipment as a new model employing the arc welded design. This first step represents the exploratory steps from the older conventional methods to the new method embodying new materials, new processes and greater freedom of design. The second fundamental source of economy, and therefore progress, in the use of arc welded design is that of improving the original design of the arc welded machine or equipment.

The importance of this second step—that of improving the original arc welded design—is one which results in very important improvements in the

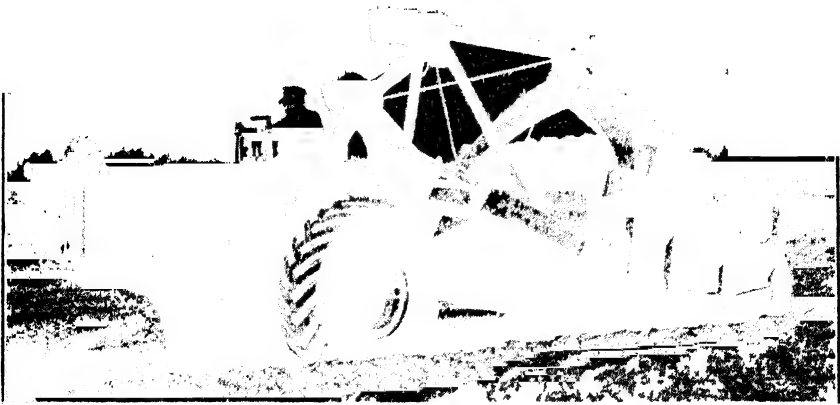



Fig. 1. Original model of wheel-type tractor.

function of the machine or equipment and equally important economy in its manufacture simply because man profits most from his experience. In taking the first step from the older, conventional method of making the machine or equipment, the designer and manufacturer extends his past experience and his past training into his new machine incorporating the most obvious advantages of the new process

After he has made this first step, and has had a chance to build the machine or piece of equipment and see it operate, the experience gained and the observations which he can make open to his mind other important changes which he could make in his first welded design which would allow him to further use the fundamental advantages of the process to make a more effective machine or piece of equipment, or to make it more economically, or both

By describing an example of a machine embodying many conventional mechanical principles by the arc welded method, the author will describe, First how very important economies were realized by first producing the machine by arc welding rather than using the conventional methods of manufacturing such a machine, and second, the further important economy in manufacture and the advantages of design brought about by improving the first arc welded design and manufacturing it under the best controlled methods learned by the experience of building and marketing the first arc welded machine

Wheel-Type Tractor Transmission Case and Frame—In developing machines to meet the modern requirements for heavy earthmoving, a unit was needed which would more economically move large quantities of earth over distances ranging from 1000-feet to several thousand feet The requirements of such a machine included

1 Power comparable to that of a track type tractor

2 Speed comparable to that of a large capacity truck

3 Maneuverability equal to or greater than any unit used for the same purpose on the market.

4 A design in which the source of power in the unit and the man power operating it could be used more economically, especially in the loading and unloading of the unit—more nearly self-loading and self-unloading

5. A ground bearing and propelling design which could withstand the speeds attainable by trucks and which would not destroy roadways by cutting them up with heavy grousers.

6. The ability to be used interchangeably with other units of equipment in the event that it should be convenient for its owner to do so.

7. Low initial cost.

8. Economy of manpower.

9. Low operating and maintenance cost.

10. The least possible weight in machine, to get maximum load carrying capacity.

11. Ruggedness of construction and ability to withstand the most rigorous operating conditions.

12. Simplicity of operation.

To meet the foregoing demands of this modern earthmoving problem, the designer produced the unit shown in Fig. 1, a wheel-type tractor mounted on two $6\frac{1}{2}$-foot pneumatic tires, powered by a 150-horsepower Diesel motor; used to operate a modern 15-cubic-yard self-loading earthmoving scraper.

While the transmission case and frame, including the bumper and belly guard structure, (and the side frames of which are also the fuel tanks) are the main subject of this paper; for the purposes of more clearly defining the subject, a description of the tractor unit itself is herewith given.

In order to meet the above described requirements for this unit, bold departures from conventional designs were undertaken. First, since this tractor is used to haul loads of earth and other construction materials, the least amount of weight which could be used for the tractor itself and still retain the ground pressure required to propel the load, would be the best design; since the less weight there is in the tractor, the more weight of "pay load" can be hauled with the amount of power available in the unit. Therefore, the principle of attaching the wheel tractor to a pivoting yoke on the unit to be hauled so that a large portion of the weight of the load, plus all of the weight of the tractor itself cantilevered over the driver wheel, was adopted. The principle is illustrated in Fig. 2 showing how 40 per cent of the weight of the load and a desirable part of the weight of the drawn unit, plus all of the tractor cantilevered directly over the drive tire fitted drive wheels. The application of this principle immediately made it possible to reduce greatly the material weight of the tractor.

Second, in the interest of maneuverability, lighter material weight in the tractor itself and simplicity of inherent design, this tractor was designed with-

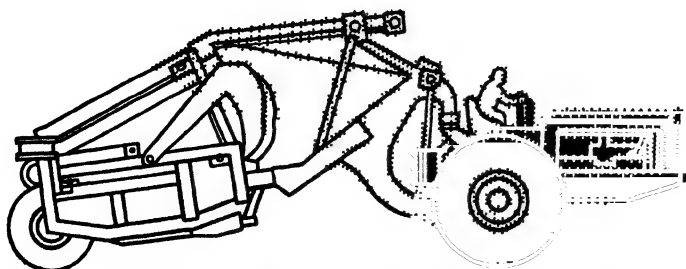



Fig. 2. Illustrating how 40% of the weight of the load and a desirable part of the weight of the drawn unit plus all of the tractor is cantilevered directly over the drive wheels.

out front wheels. The fact that the motor cantilevered over the drive wheels and that the tractor was held in a horizontal position by the yoke of the unit which it was pulling, made it possible to eliminate the entire front wheel assemblies usually found on wheel type tractors. Elimination of the front wheels, therefore, resulted in the maneuverability equal to or greater than that of track type tractors, since the unit can be completely turned around by a pivoting about the wheel center of one wheel on a circle whose diameter is controlled only by the length of the wheel base from the rear wheels of the unit being pulled and the clearance between the driver wheels of the tractor.

Third, in the interest of placing all of the weight possible in front of the drive wheels, and to develop more economy of material and space, the frames upon which the motor of the tractor was mounted were made as box sections and used as fuel tanks. This eliminated fuel tanks as they are usually known on tractors, and in addition, placed the weight of the fuel itself ahead of the drive wheels so that it contributed more than its actual weight to increasing the traction on the drive wheels because of the cantilever effect of its being ahead of the drive wheels. This also shortened fuel lines from tanks to the motor, yielding a more ideal design.

Fourth, again in the interest of simplicity of operation the steering mechanism for this tractor was placed in the transmission in the form of friction clutches so that the least amount of weight and material would be used in achieving the steering operation and so that the operator might be placed directly over the center of the driving line, near the controls for both the tractor and the drawn unit.

Fifth, the transmission case was so designed that one large axle on each side of the case would support the 6½-foot pneumatic tire with sufficient rigidity and strength and without excessive expenditure for material, to maintain standard automotive road width and yet give maximum maneuverability and wheel base width.

Sixth, as a means of reducing weight and of obtaining the material strength required for this particular design, a low alloy high tensile structural steel of from 80 to 90,000 pounds per square inch tensile strength was used in the manufacture of the major parts of this tractor frame. This allowed the reduction of weight with comparable strength of from 25 to 33⅓% over ordinary 60,000 pounds per square inch tensile strength structural steel, for all major parts of the tractor case and frame.

To further describe the production of the unit, it should be stated that the radiator, the motor, and the gear shifting transmission assembly were purchased and assembled to the main frame of the tractor after it was fabricated in the factory. A power control unit for cable operation was attached to the rear of the transmission case in order to actuate the earthmoving unit drawn behind the tractor. The operator's seat structure was purchased. All other major structures of the unit, including the wheels and deck plates were manufactured in the designer's plant. Fig. 3 shows a closeup of the tractor itself with one drive wheel removed in order more clearly to show the main subject of this paper. In Fig. 3 the original arc welded design is shown, indicating the relative size of the transmission case and the gas tank and frame structure upon which the motor is mounted. Fig. 4 is a close up of the front part of the unit showing the belly guard and bumper structure, which is not shown in Fig. 3. Since this structure became practically standard with the unit, it is included as part of the main frame and transmission assembly covered in this paper.

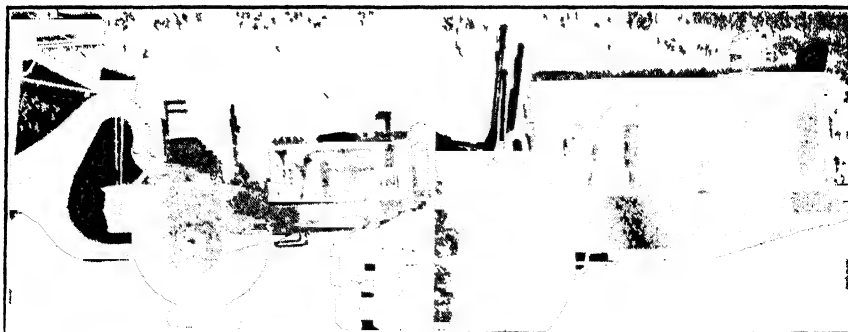



Fig. 3, (left). Drive wheel removed to show main gear case and frame.
Fig. 4, (right). Same as Fig. 3 with bumper and belly guard.

The details of the original design of the transmission case, frame and fuel tank structures, and bumper structure, together with the accessories required to put it together as an assembled unit, are shown in Fig. 5. The four major units or structures in this unit were the main gear transmission case, the right fuel tank and frame structure, the left fuel tank and frame structure, and the belly guard and bumper structure combined.

The Designer's Question—"How to Make These Structures?"—In designing a machine to meet the above outlined requirements for this wheel tractor and after visualizing the general structure of the wheel tractor transmission case, frame, and bumper assembly from a material standpoint to the extent of deciding upon a high tensile steel, the designer had to decide by what means he should make these structures.

A more detailed examination of the specific requirements of such a design showed that the structures must have the following characteristics:

A. Using high tensile material for the construction of these units, relatively thin sections would give the required strength for each of the four major structures if they were made of box-like structures to use the maximum material strength of the high tensile steel.

B. The finished structures all require a high degree of rigidity.

C. They must be so constructed that the vibration of the motor and the severe operating conditions of high speeds with heavy loads could not loosen up joints or work parts of the unit loose in service.

D. Both fuel tanks and transmission gear case had to be oil tight.

E. The fuel tank and side frame structures had to be sufficiently permanent of construction so that the bouncing, vibration, and the stresses from the weight of the motor would not cause them to deform and throw the motor out of alignment with the shifting transmission or the steering transmission; or would not develop leaks because of the strenuous operating conditions.

F. The gear case had to be as easily machineable as possible because of the several bearing seats; cover plate seating, drilling and tapping; fuel tank bolt base seats; and other machining operations to be done upon it.

G. The gear case had to house the friction steering clutches, the main drive gears for the wheels; and without diaphragming to place the main axles for the wheels sufficiently low to maintain proper clearance without diaphragming during the most strenuous of operating conditions over rough

ground. It must also be strong enough to seat the power control unit on the rear of the case to give cable control to the earthmoving scraper or other drawn unit.

H. All of these structures had to be made with a degree of accuracy which would maintain very narrow tolerances with the minimum of workmanship in order to insure good mechanical function.

I. All of the units had to be made to resist heavy shock load and severe impact since this machine would be operating in rough construction work under extremely rigorous conditions. All joints and structures had to be permanent.

J. Each of these major structures must be capable of being cleaned and painted and finished to withstand normal wear and weather conditions for year around outdoor service.

K. Each of these major structures should be as streamlined and smoothly styled as is compatible with the other functional requirements of the design in order to make the units have as wide an appeal for modern merchandising practice as possible.

L. Each of these structures should be made of material and construction which lends itself most favorably to field service and repair in the event of damage caused by abuse or accident in the field beyond that which should be expected of any design in reasonable use.

M. Each of these structures should be made using as little weight as possible in order to achieve the structural strength required and yet release all of the weight possible for load carrying capacity.

Of the conventional methods available for the manufacture of such structures, either the use of steel castings or of arc welding would be the

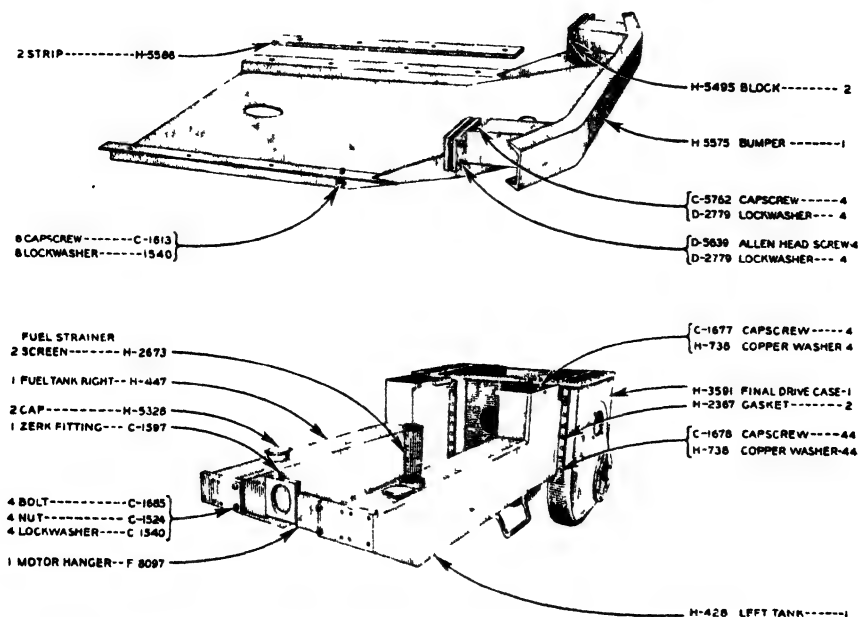



Fig. 5. Detail of the parts of original arc welded model of transmission case.

only reasonable and practicable methods of manufacture. No other method would give the rigidity combined with the permanence of joint and oil tight requirement embodied in this design.

Cast from Alloy Steel or Arc Weld from Alloy Plate?—Each of these units could be manufactured by arc welding; or with certain concessions in design, by alloy steel castings so that they would be interchangeable in assembly, uniform in shape and size, and would have about equal characteristics so far as handling in the factory or assembly is concerned. Each would have to be made with a rigid control of material and workmanship in order that they present a good performance in the field. A comparison of the general features of the cast steel construction compared to the arc welded construction aside from a detailed comparison of costs, (which will follow later) for each separate structure, indicates the following general differences.

A, Weight of Structures—Each of the four major structures involved would be heavier using the cast construction, even using a comparable strength alloy cast steel because of the many thin sections involved in each of the four structures and because of the necessity for fillets to equalize the thin sections with the very thick sections, particularly in the transmission case. This difference is estimated to be at least 7 per cent heavier over the arc welded construction in the finished castings.

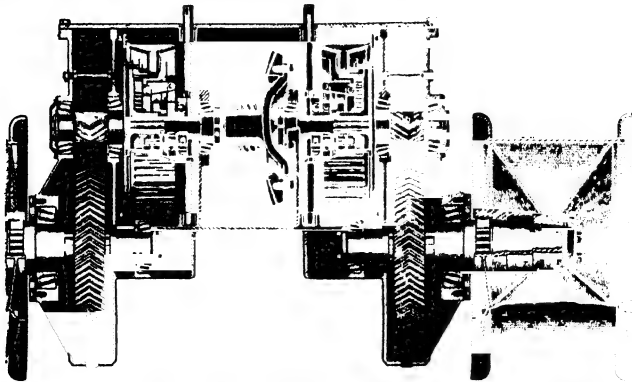



Fig. 6. Cross section of main transmission case.

B, Freedom in Use of Specialized Materials—If these structures were made of cast steel they would have to be made completely homogeneous whereas using the arc welded method of construction, high tensile alloy steel plates and bar stock may be used for the major parts of the structures where structural strength is necessary and a less expensive and more machineable steel such as SAE 1020 may be used for such items as the bearing blocks, bolt plates for the ends of the gas tanks, and other parts of the case or other structures where mechanical strength is not particularly necessary. An example of such a part is the baffle plate inside of the fuel tank to avoid surge while the units are traveling. These baffle plates are made of mild steel 1/8-inch thick, welded inside of the alloy plate box structures. An examination of Fig. 6, which shows a cross section through the final drive case showing the parts after assembly, shows some of the bearing blocks in the case and a comparative thickness of the main structural wall-plates of low alloy high tensile steel compared to the thick heavy bearing blocks which in the arc welded construction can be made of mild steel. These parts are thus more

machineable and less expensive than if they were made from the alloy plate, and still they have all of the structural strength required of them.

C, Maintenance of Clearances and Tolerances in Structures—By arc welding parts made from alloy steel plates as rolled at the mill, under controlled set-up and welding procedures, the maintenance of the close clearances indicated by Fig. 6 is assured. By taking plates and other parts of uniform shapes, strength and size, and setting them up under positive control and fusing them together with welded joints which increase the section of the members only at the junction with the adjoining members of the design, it is possible to set up and maintain the close tolerances and space-utilizing design such as illustrated in Fig. 6. The problems of casting thin sections of high tensile alloy steel into sections requiring as close tolerances as indicated in Fig. 6 present difficulties which, if met by the most resourceful of modern foundry practice still require a cost, according to official foundry cost schedules, which cannot compete with the arc welded design.

D, Inspection—the Control of Quality—Certain items in the design, particularly the baffles in the fuel tank structures would be almost impossible to produce by the casting method. The inspection of such inside features and the accurate production of uniform section thickness and 100 per cent uniform quality throughout the critical part of the design would be extremely difficult in the cast design. However, in the manufacturing of them by the arc welded method the materials themselves control the section thicknesses since they are already assured by the purchase of uniformly manufactured rolled plate and bar stock. In addition, the fact that these units can be built up as sub-structures and then welded into complete structures allows the progressive inspection of every detail of the structure as it progresses through each step of its manufacture.

E, Welded Bolt Circle Plates vs. Cast Steel Bolt Circle Plates—Since these structures are bolted together in certain places, the arc welded construction presents another important advantage in that the surface of a rolled steel plate or bar as purchased from the steel mill is sufficiently uniform and flat to seat the head of a capscrew and a lock-washer on it without machining. The entire bolt circles or bolt bases on the fuel tank structure if cast would have to be either spot faced or milled flat to prepare it for a satisfactory and dependable capscrew base.

F, Repair of Accidentally Damaged Structures in the Field—In the event of abuse or accidental damage to the unit in the field, because of unexpected damage done to any of the major structures involved, the arc welded design would present complete assurance of quick and easy repair by welding that would not necessarily be true of the cast steel design. The fact that it was originally made by welding indicates the weldability of its parts. A skilled serviceman in the field would not hesitate to bend or straighten a welded structure by ordinary field welding methods and arc weld it to a state of complete repair, if he were called upon to work upon it. With the cast steel design, however, he would have no way of knowing whether the original strength of the castings had been attained by heat treatment of an alloy steel and consequently would have two questions difficult to answer with regard to a welded repair on such cast structures: First, "is it weldable?" (a question he could answer by trying to weld it), and second, "if it were welded would the heat of welding reduce the strength so that subsequent failure would follow?" If modern field repair service by welding were not applicable to such a unit, any other method of repair would be very expen-

sive from a standpoint of time and labor involved, since it would require straightening mechanically in some fashion and perhaps bolting patches onto the structure; or else it would require the replacement of the structure itself.

G, Freedom of Manufacture and Independence of Production—In view of the very specialized foundry processes involved, that of making high-grade, high tensile special alloy steel castings requiring considerable technical experience and requiring a great initial outlay for equipment, the designer could correctly assume that it would be more economical for him to purchase these alloy castings from already experienced and existent foundries in the cast and cleaned condition ready to machine rather than to try to set up his own foundry for the manufacture of such castings. (Even such large users of alloy castings as the railroads usually purchase their castings from steel foundries, rather than trying to operate foundries of their own). The welded structures he could make himself in his own plant in varying quantities to suit his own needs with a small enough initial outlay of capital for equipment and material to be practical for the ordinary small or the medium sized industry today. This automatically gives him a freedom of production of from a very few parts or a very few completed units at first, to any reasonable number which he desires to manufacture according to the demands for his field. From the standpoint of development of design, this is a very important feature in favor of arc welding since it gives the manufacturer the opportunity to use equipment which may already be in his plant or which can be purchased for a relatively small initial outlay compared to the initial cost of a few experimental cast pieces of the complexity indicated by these four main structures for the wheel tractor transmission case and frame by the cast steel method. The cost of castings in small numbers is much greater than in lots of 100 for example, due to pattern costs.

H, Speed of Development and Proving of New Designs—The length of time required in developing new designs and getting the experimental units built and tested in the field is a very important consideration in the development of new units. In the case of the wheel tractor, transmission case, frame and fuel tank assembly, the initial investment in time using steel castings as compared to that for the arc welded design would be considerably greater. Several items contribute to this. First the specifying of fillets and risers and the amount of detail required in the drawing for such a structure as the transmission gear case alone, would require considerably more engineering and drafting time than a similar drawing for the arc welded construction method. Second, the length of time consumed in manufacturing the pattern and cores required for such a complex structure would probably be about equal to the length of time required to actually manufacture the unit from rolled steel and bar stock by the arc welded method.

I, Freedom to Make Changes in Design While Building the First Unit—The freedom of choice on the part of the designer to make changes in his experimental units is considerably greater in the arc welded method than in the steel cast method, largely because of the requirement of making new and expensive patterns and all new castings in the event of a change in a cast steel design. This requires much more time and money than the simple method with the arc welded design of simply altering the drawings and cutting new pieces and building a new structure. In many cases this is not even required, for in minor changes parts may be welded onto the original design or pieces may be cut out with an acetylene cutting torch and the new pieces cut and welded into the design.

General Requirements for Most Economical Arc Welding Manufacturing Practice—Since all of the foregoing consideration indicates that the choice of the arc welded method of producing the four major structures for the wheel tractor transmission case, frame and bumper assembly, a further consideration of the important features of the arc welded method of manufacturing such units should be considered.

A, The Welding Engineer—Probably the most important factor in the use of arc welding for the manufacturing of any type of unit, whether it is very large or whether it is very simple, is the welding engineer. The most important attribute of the welding engineer must be that he be completely sold on arc welding as a means of manufacturing equipment. This confidence in arc welding should be the result of experience, and in order to function properly he must have the power to act within a wide scope of responsibility. This may be limited to the complete charge of designing and manufacturing of a very small item as a starting step if the company is contemplating changing its products over to an arc welded design. The wide range of authority and power to act is absolutely necessary for him successfully to make the step from an older conventional method of manufacturing a product to the arc welded method.

This welding engineer functions best ordinarily if he is trained within the organization, but if such a man is not available in the organization, qualified men may be obtained elsewhere. He must know arc welding from the manual processing standpoint from experience. He must be a good mechanic, he must be a resourceful workman, he must be able to use the accessory machinery and train people in its use to manufacture the parts which he wants made for his structures. He must understand arc welding design from a material strength standpoint and from a practical processing standpoint. All of this is information which he may learn on the job by studying and by practical experience. In many ways it is better for him to get that information on the job than in any other way, because he tends to experiment more and take fewer things for granted as being impossible to do.

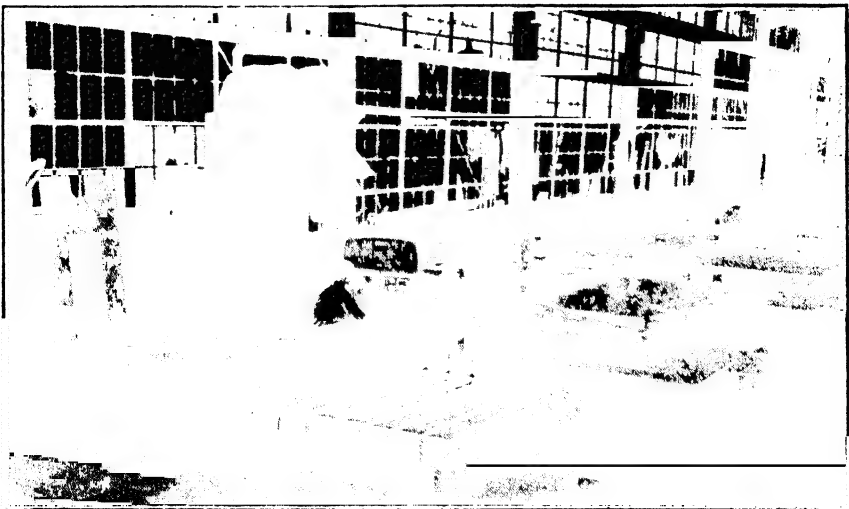



Fig. 7. Multiple flame cuttin~ ~akes mass production an economic reality.

He must know how to calculate costs, and be able to organize procedure controls. He must be a man who can win the confidence and respect of the workmen under him and lead them rather than push them to accomplishment, for in that way he may incorporate into his accomplishment the natural resourcefulness of the average workman in offering suggestions as to how to improve procedures, which is one of the most important sources of improved design and processing in the arc welding field today. He must be able to demonstrate by objective facts and tests the value and solidity of the structures which he builds and the economies involved therein. He must be able to train men in procedure control and to delegate responsibilities to capable hands in such a way that workmanship and material are used according to the best possible practices of economy.

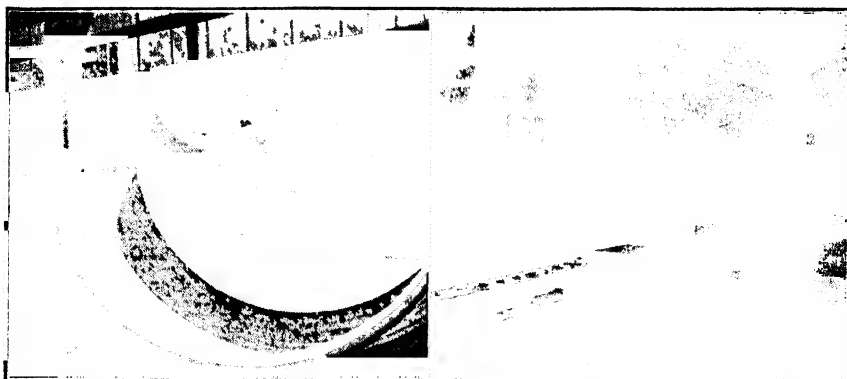



Fig. 8. (left). A roll makes curved parts economical. Fig. 9. (right). One piece bent is usually more economical than two pieces welded together.

B, Processing Machinery—The physical equipment required for arc welding does not offer a particularly large problem. A source of oxygen and acetylene for flame cutting and a good source of electrical power to operate the arc welding machine are necessary for the plant. Both of these items are easily available in the average industrial plant today, or can be made so with relative ease. There is a wide variety of arc welding machinery on the market from which this welding engineer may choose the items best adapted to his purposes.

Mechanical flame cutting units, such as shown in Fig. 7, increase the production of flame cut parts markedly and bring about very good economy for the production of large numbers of units by the arc welded method. Plate shears and bar shears offer economy in the preparation of parts for welding structures on a production basis. For the best functional designs involving curved structures, a steel rolling unit such as shown in Fig. 8 also offers real economy in shaping parts for the mass production of arc welded structures.

One of the units of machinery that produces the greatest economies in producing parts for arc welded structures is a bending brake such as shown in Fig. 9 since it allows the bending of plates rather than the cutting of them into smaller pieces and welding them together. Whenever a single plate can be bent to take the place of two or more smaller plates a marked reduction in cost of the structure results due to fewer inches of welding, and less

handling of the parts of the structure. Such a brake may also be used as a punching unit, Fig. 9, or for hot or cold bending, pressing, embossing and shaping.

C, Welding Set-up and Positioning Fixtures—One of the major steps of control and mass production uniformity and economy in the arc welding method of fabrication is that of using fixtures for the setting-up of the parts and positioning fixtures for the most favorable welding of structures. These fixtures may be the same fixtures in the case of simple units or they may be separate, as for example, the case set-up fixture shown in Fig. 10. Such a fixture may be made simply and economically by the welding engineer. By attaching stops and clamps to it the workman who sets up the parts may

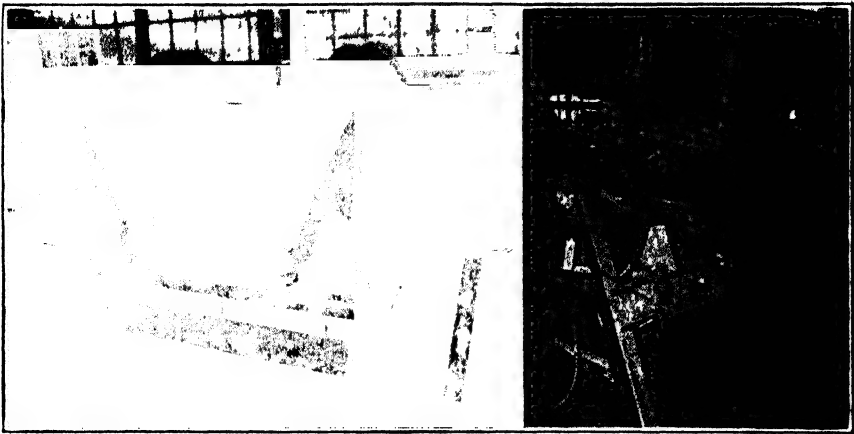



Fig. 10. (left). Inexpensive set-up fixture provides quick positive positioning. Fig. 11, (right). All welded positioning unit.

place them more quickly and more nearly error-free, and more positively than he can in any other way. This reduces the time and, consequently, labor involved and reduces the opportunities for mistakes. It gives positive alignment of parts and maintains tolerances aind clearances in a positive manner.

Another very important source of economy is illustrated in Fig. 11, which shows a positioning fixture for a gear case which allows universal positioning for downhand welding of the majority of joints in the unit. This is a very important source of economy as is shown in Table I showing what the difference in cost of deposition of welds made in the vertical position, in the horizontal fillet position, or in the flat (downhand) position amounts to. Not only is there a considerable percentage of increase in speed of deposition of welds in the downhand position over other positions, but there is a greater assurance of complete penetration into the bottom of the weld, a better appearing weld usually results and there is usually less time lost by the operator due to fatigue, preparing himself to weld, loss of nervous energy, and machine adjustments.

Table I—Percentage of Welding Time Saved by Positioning Vertical and Horizontal Fillet Welds for Downhand Welding. (Minutes Per Inch of Weld Based on Time Studies in Manufacturers' Plant of Arc Time Plus Fatigue Allowance).

Size of Weld	Min./Inch of Weld Welded Vertical	Min./Inch of Weld Welded Horizontal Fillet	Min./Inch of Weld Welded Downhand (Positioned)	Percent Saved by Positioning Vertical Weld for Downhand Welding	Percent Saved by Positioning Horizontal Fillet Welds for Downhand Welding
3/6"	.254	.140	.105	58.7	25.0
1/4"	.292	.155	.115	60.6	25.8
5/6"	.327	.170	.125	61.8	26.5
3/8"	.412	.231	.140	66.1	39.4
1/2"	.660	.342	.191	71.1	44.2

D, Operation Sequence Control—It is relatively simple after a fixture is prepared to set-up the parts of a structure and a positioning fixture is available in which to weld it to establish a step-wise procedure of operation from the placing of the first part in the set-up fixture until the completion of the last weld. Figs. 12A, 12B, and 12C show check sheet incorporating

Case Welding

Elements	CCC.	Units	Total
1. Prepare jig for setup			
2. Get & pos. end plates to jig			
3. Burr holes in end plates & clean bushings			
4. Get & pos. inside end plates			
5. Clean, pos. axle shaft & bushings			
6. Clean, trim & pos. to center plates			
7. Get & pos. spacers for center & end plates & tack			
8. Pos. & tack bottom plate			
9. Adj. center plt. & stop; pos. axle boxes & bushings			
10. Clean & pos. axle boxes			
11. P. & T. ball gear hsng. bands			
12. Clamp in place & complete tacking bottom plt.			
13. Turn jig; pos. & tack side plates in place			
14. Turn jig, pos. & tack 1" bars			
15. Turn jig, tack inside plates to side plates & loosen stops			
16. Turn jig & remove main axle shaft			
17. Weld axle boxes			
18. Turn jig, pos., tack & weld facing block			
19. Pos. boxbeam spacer & finish welding axle boxes			
20. Turn jig, pos., tack & weld 2 gussets			
21. Pos. & tack sub. bottom & draw bar str.			
22. Pos. & tack two gussets to frt. of axle boxes			
23. Remove case from setup jig			
24. Finish tacking inside plate & 1" bar			
25. Stamp and aside structure			
		Total	

Date.................... Case No..........
Job No.................. Operator's No..
Foreman's O.K........... Shift Day.. Nite..
Plant...................

Fig. 12a. Step-wise procedure check sheet for set-up of main transmission case.

Inside Welds

Elements	CCC.	Units	Total
1. Pos. & clamp case in jig, pos. jig to frt. plt. thru two holes			
2. Pos. center spacer across case at top			
3. W. stringers & 1st passes on outside of case turning jig			
4. W. four butt welds bull gear hsngs. to frt. & back plts. turning jig			
5. W. lt. axle box & bot. of reinf. bar to lt. inside plt. turning jig			
6. W. rt. axle box & bot. of reinf. bar to rt. inside plt. turning jig			
7. Turn, W. axle bxs. to bot. plt., frt. side			
8. W. axle bxs. to bot. plt., back side, S. V's. frt. & back plt. to bot. plt., turning			
9. W. axle blks. to axle bxs. & bot. plt. both sides turning jig			
10. W. bot. plt. to frt. & back plt. turning jig			
11. W. axle bxs. to bot. plt. inside sides turning jig			
12. Tie in axle bx. & axle blk. welds turning jig			
13. W. 1st passes rt. sides of center plts. to bot. plt. turning jig			
14. W. 1st passes lt. sides of center plts. to bot. plt. turning jig			
15. Slag all (4) 1st & W. 2nd passes lt. sides of C. plts. to bot. plt. turning jig			
16. Turn, W. rt. inside plt. to bot. plt			
17. W. 2nd passes rt. sides of C. plts. to bot. plt. turning jig			
18. Turn, W. lt. inside plt. to bot. plt			
19. Turn, slag all tacks on inside & center plts			
20. Turn, W. lt. sides of inside plts. to frt. plts			
21. W. rt. end plt. & 1st passes on rt. sides of C. plts. to frt. plt			
22. Turn, W. rt. end plt. & lt. sides of inside plt. to back plt			
23. W. 1st passes center plts. to back plt. turning jig			
24. W. lt. end plt. & rt. sides of inside plts. to back plt			
25. Turn, W. rt. sides of inside plts. to frt. plts			
26. W. lt. end plt. & 1st passes on lt. sides of C. plts. to frt. plt			
27. Turn, slag 1st passes center plts. to frt. & back plt			
28. W. 2nd passes center plts. to back plt., lt. sides			
29. Turn, W. 2nd passes center plts. to frt. plt. lt. sides			
30. Turn, W. 2nd passes center plts. to back plt., rt. sides			
31. Turn, W. 2nd passes center plts. to frt. plt., rt. sides			
32. Slag, P. T. & W. (2) splash gussets turning jig			
33. Slag, P. T. & W. (2) splash gussets turning jig			
34. Turn, W. bar to back plt			
35. Turn, W. bar to lt. outside plt., 1st pass bar to lt. inside plt			
36. Turn, W. bar to frt. plt			
37. Turn, W. bar to rt. outside plt., 1st pass bar to rt. inside plt			
38. W. bar to rt. inside plt. 2nd pass			
39. W. S. V's. bar to rear plt. & tie in welds on sides of bars turning jig			
40. Turn, W. bar to lt. inside plt. 2nd pass			
41. W. S. V's. bar to frt. plt. & tie in welds on sides of bars turning jig			
42. Turn, remove center spacer clamp, W. under clamp			
43. Turn upright, W. tie in welds top & inside of case			
44. Remove & aside case from jig			

Date.................. Case No..............
Operator's No..............................
Foreman's O.K..............................

Total..............
Unit No..............
Job No..............

Shift: Day.................. Nite..................
(H 3591)
Plant #2
TS 26

Fig. 12b. Step-wise procedure check sheet for making welds on inside of transmission case.

Outside Welds

Elements	CCC.	Units	Total
1. Pos. & clamp case in jig			
2. Turn, W. 1st pass bull gear hsngs. to lt. ins. plt. & rt. end plt			
3. Turn, W. butt welds, bull gear hsng. bands to frt. plt			
4. Turn, W. 1st pass bull gear hsngs. to rt. ins. plt. & lt. end plt			
5. Turn, W. butt welds, bull gear hsng. bands to back plt.			
6. Turn, slag tks. on all bars, W. bar to frt. plt			
7. Turn, W. bar to lt. end plt			
8. Turn, W. bar to back plt			
9. Turn, W. bar to rt. end plt			
10. Turn, slag 1st passes all way around end & ins. plts			
11. W. 2nd pass all way around lt. end plt. turning jig			
12. W. 2nd pass all way around rt. end plt. turning jig			
13. W. rt. ins. plt. to bull gear hsng. turning jig.			
14. W. lt. ins. plt. to bull gear hsng turning jig			
15. Turn, W. 1st pass sub bot. to axle boxes			
16. Turn, slag tks. & 1st passes back to bot. plt. & axle bxs to sub-bot			
17. Turn, W. 2nd pass back plt. to bot. plt.			
18. Turn, W. 2nd pass axle bxs. to bot. plt. back side			
19. Turn, W. 2nd pass sub bot. to axle bxs			
20. Turn, W. hondu to sub-bot. & hitch blk. to bot. plt., rear side			
21. W. hitch blk. to sub-bot. outside			
22. Turn, W. frt. plt. to bot. plt			
23. W. rear of axle bxs. to ins. plts.; W. rear gussets to axle bxs turning jig			
24. W. hitch blk. to sub-bot. inside turning jig			
25. Turn, W. ins. side of lt axle bx & lt. inside plt. to bot. plt			
26. W. rt. sides of rear gussets to bot. plt., W. bot. of lt. axle bx to ins. plt			
27. W. seams on frt. sides of sub-bot. turning jig			
28. Turn, W. ins. side of rt. axle bx. & rt. inside plt. to bot plt			
29. W. lt. sides of rear gussets to bot plt, W. bot. of rt axle bx to ins. plt			
30. W. frt. gussets to sub-bot. turning jig			
31. W. sides of sub-bot. to bot. plt. turning jig			
32. Turn, W. axle bxs. (inside) & frt. plt. to sub-bot			
33. W. 2nd pass top side of bot. plt. to frt. plt			
34. Turn, W. sub-bot. to inside plt			
35. Turn, W. corners of sub-bot. to frt. plt			
36. W. top hitch blk. to bot. plt. frt. side, W. edges of hitch blks. to sub-bot			
37. W. corners & tie ins. on frt. plt. & frt. of sub-bot. & axle bxs turning jig			
38. Turn, W. edges of hitch blks. to sub-bot. ins. tie in back plt corners			
39. W. S. V's. back to bot. plt., finish tieing in welds			
40. Remove clamps, W where clamps were, W. corners of bars			
41. Remove & aside case to floor, turn & blk case upright on floor			
42. Remove jig from frt plt			
Date .... Case No Operator's No.... Foreman's O.K..... — Total ... Unit No. Job No.			

Shift: Day........ Nite

(H 3593)

Plant #2
TS 27

Fig. 12c. Step-wise procedure check sheet for making welds on outside of transmission case.

step-wise procedures and shop production record sheet used by workmen who make the tractor transmission case. Such a step-wise procedure is exceedingly important because it makes for uniformity of structure. It also allows the use of the positioning fixture to its best advantage, that of getting the majority of the welds deposited in the downhand position and in the same sequence from one part to the next. With such a step-wise procedure, the operator learns his job in an orderly fashion and executes it the same order on each successive structure. This makes it possible to spend most of his conscious attention on the deposition of metal, and assuring himself that he is depositing good sound welds, rather than planning which move he is going to make next. Operation sequence control is one essential step in modern industrial mass production which has been proved to be indispensable in the production of machines with interchangeable, standardized parts. It can be organized for production of machines by arc welding very easily, and thus establishes the well known economies of standardized mass production.

E, Control of the Size of Welds Deposited on Structures—The alert welding engineer quickly recognizes that the deposition of the correct size of welds as a structure is of great importance. In the first place it is necessary to deposit sufficient metal in a joint to assure its proper function. The average welding operator wants to be on the safe side and consequently, unless specifically advised as to the size of weld which he is supposed to deposit, he will almost invariably deposit a larger weld than is really necessary. There are many means of accomplishing control of the size of welds but probably the most effective one of all is that of the use of welding symbols on prints from which the man works.

The importance of the size of weld compared to the cost of the weld is shown in Fig. 13 which diagrammatically shows the volumetric progression of size of welds with increase in dimensional size. Roughly a 1/4-inch weld is equivalent to 4 times the volume of a 1/8-inch weld. Fig. 14 shows how a weld size may be shown on a print by a welding symbol and also shows the

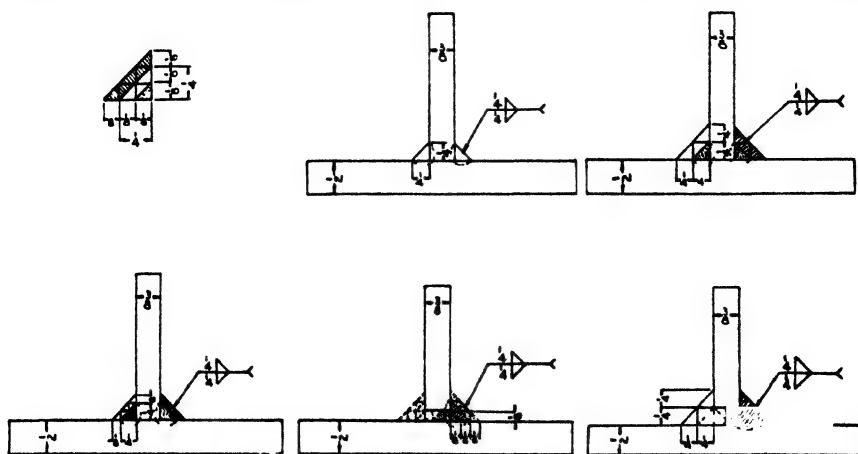



Fig. 13, (top, left). Volumetric progression of size of welds. Fig. 14, (top, center). Directly fitting joint. Fig. 15, (top, right). Diagram showing the cost of overwelding. Fig. 16, (bottom, left). The result of overwelding. Fig. 17, (bottom center). Improper fit-up requires 2½ to 3 times more weld metal. Fig. 18, (bottom, right). A gap of ⅛ the thickness of the thinnest plate in the joint requires over 5 times the necessary weld metal.

Fig. 19 Mass production of machining.

volumetric size of a properly welded joint according to the specifications Fig 15 illustrates the result of over-welding where the weld is twice the size specified by the symbol, where actually about four times the amount of weld metal has been deposited Fig 16 shows a common degree of over welding, simply that of being $1\frac{1}{2}$ times the size specified on the print or necessary for the joint and yet requiring approximately twice the amount of weld metal The control of welding metal deposit that is, the size of the welded joint, by some positive method, is one of the most important sources of economy in the arc welding method of fabrication of machinery or other equipment

F, Control of Joint Fit-up—Another extremely important factor in the cost of arc welding structures which the alert and resourceful welding engineer will keep under close control is the degree of perfection of fit-up at the joints. This is inherently important from the standpoint of getting good, strong, sound joints, and of requiring the minimum time to produce structures by the welded method Fig 17 shows a welded joint similar to that shown in Fig 14 with a perfect fit up The joint in Fig 17, however, shows a gap in the fit-up of one third the thickness of the plate, which, again following the natural tendency of the average workman who wants to do an honest, safe job, will almost always cause the deposition of more metal

than that joint requires. Further, the additional amount of time required to deposit the first bead or two in the joint, and the additional time required to weld the total joint results in a very significant increase in the cost of the unit.

Fig. 18 shows a similar joint with a gap equivalent to two-thirds of the thickness for the thinnest plate in the joint showing geometrically how at least four times the amount which was specified is deposited and usually about five times the amount of weld metal is deposited in such a joint. A simple procedure of checking the template by which the parts are cut and by correcting them to the original design, as made in the first experimental model, is the most important step in the control and elimination of poor fitting joints. If this checkup and correction is made on the original set of templates from the experimental machine; and any misfits which escape that first checkup and occur in subsequent orders of the unit are corrected on prints and templates immediately when they are found, the poor fit-up element in welding can be reduced to a minimum, especially when positioning fixtures are used to place the part in their proper position. If the parts are cut properly and are positioned with positive accuracy by a fixture, a design can be perfected to automatically yield good fit-ups.

G, Training of Welding Operators—The training of welding operators by the welding engineer when they join the organization is a very important step in the economy of his overall production. If the engineer trains his men to weld from the very beginning, or if he hires arc welders and qualifies them by tests which satisfy him that they can do the required work, the next important step is that he shall in some orderly way train them in the processes, methods, and controls associated with his job. This should involve a thorough training covering the use of the equipment in the plant, according to that particular plant practice; the method of control; the use of fixtures, and the step-wise procedure of manufacturing the unit. If a

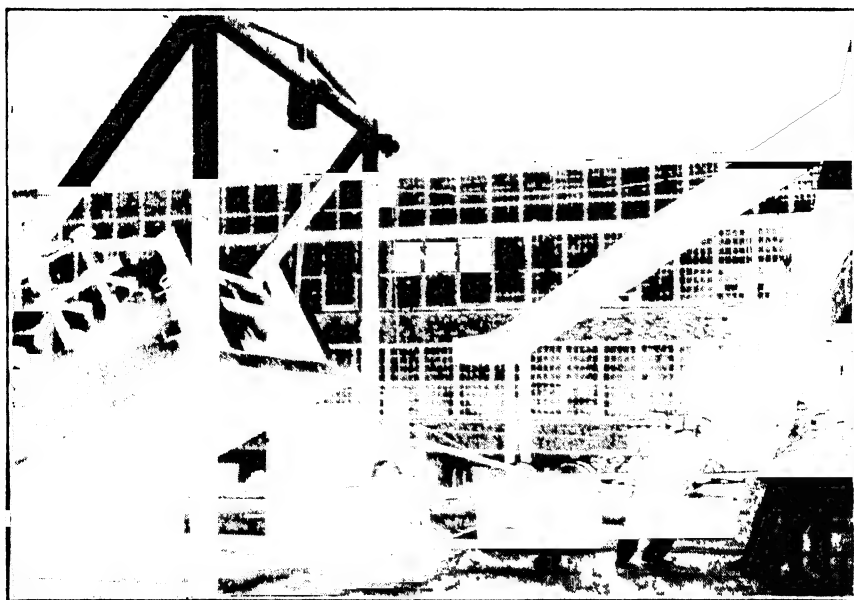



Fig. 20. All welded normalizing furnace.

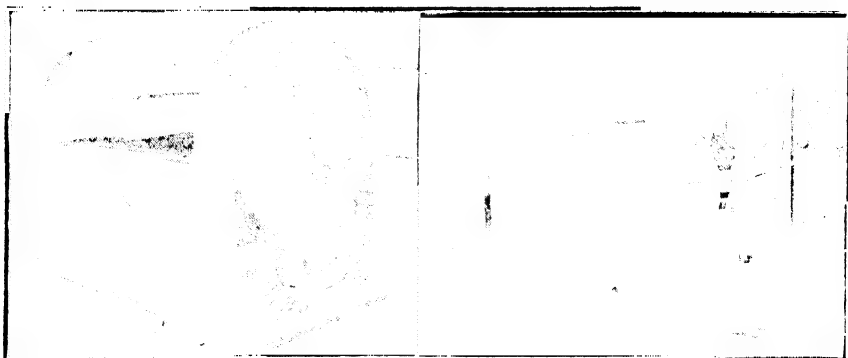



Fig. 21, (left). Welded gear case. Fig. 22, (right). Major machining operation on welded structure.

careful and orderly training program of this kind is carried out whenever a new man comes to the organization, the welding engineer and management may be assured of a much more uniform, economical, and satisfactory service from that workman, because he then can be told exactly what is expected of him.

H, The Machining of Welded Structures—The machining of arc welded structures is much like the machining of the product of any other conventional method of making such units, such as castings, and the practices of making fixtures for quicker machining produces economies which are very important.

The use of a multiple drill to place half of the holes in the top of a transmission case, shown in Fig. 19, to which the deck plate is bolted is a good example of how arc welded structures may be machined on a mass production basis using multiple drills and drill jigs with hardened bushings to speed up this type of production. In the use of certain alloy plates for arc welding, and in the building of certain structures, such as a complex gear case, it is necessary to stress relieve the completed welding by normalizing at 1200 degrees in a furnace and allowing to cool gradually to release the stresses within the structures. Fig. 20 shows welded transmission cases being removed from an unconventional type of welded normalizing furnace. After such normalizing, it is frequently beneficial to clean the structure thoroughly, removing the resulting normalizing scale, such as shown in Fig. 21, the slag and spatter-drops from the welding process from the structure before machining. This may be done by a sand or grit blasting process, or by a strong buffing process, or in some cases a flame scaling process. It is often desirable to put a primer coat of paint on a welded structure of some complexity immediately after cleaning and prior to such machining operations as shown in Fig. 22, the boring of the bearing seats of a welded transmission case.

The above outlined items of good welding practices are all within the scope of the modern manufacturing workman's abilities and capacities and within the scope of the common tools with which manufacturing is done today. They represent a brief review of the fundamental things the alert welding engineer or the management of a welding establishment should study and maintain under control in order to reap the best results from the arc welding process. These problems for the arc welding design and manufacture of equipment are no greater for the welding process than the other variables and problems which must be organized and controlled in other methods of

manufacturing, and are simpler in many respects. There is nothing in the solution of any of the above listed problems which is beyond the ability of an alert student of his job; and which may not be worked out and learned from experience on the job if the one who is solving them has the cooperative backing of the management of his organization.

After having considered the foregoing items and elements of successful arc welding design and practice in the manufacturing of arc welded structures, the designer of the wheel type tractor for greater efficiency in earthmoving decided to arc weld the four main structures shown in Fig. 5. A detailed study of the comparative costs of the arc welded methods of construction for these four structures compared to that of the cast steel construction follows.

Source of Welding Costs and Costs of Materials Used—Early in 1940 the design of this new model wheel tractor was undertaken. The structure shown in Fig. 23, namely the gear case for the final drive transmission, including the axle housings for the main drive wheels, and the right and left combined frame and fuel tank structures were first designed.

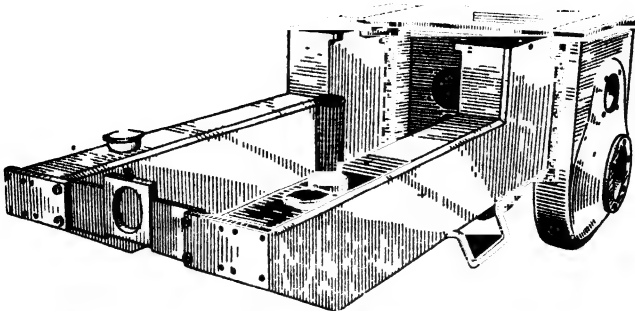



Fig. 23. Main gear case with combined fuel tanks.

The cost of this transmission final drive gear case and frame assembly which will hereinafter be given, is an actual cost on a production basis. One experimental unit was first made and tried. (This, of course, was complete with the gas tank, bumper and belly guard, assembled into a complete unit and tried in the field). It proved to be sufficiently successful that a pilot production order of five such units was produced. On this order of five, the tools, jigs, and fixtures, welding control procedure, and other production requirements were established. A full fledged production order of 50 followed the pilot order of five. The demand for the unit was so great that a second production order of 50 was issued and practically completed by the end of 1940. On January 1, 1941 there were already 88 of the original welded design wheel tractors in the field in operation. It is, therefore, on this production basis that the cost of the structures are given.

Specific Items of Cost in Welded Structures—A, Mild steel comparable to SAE 1020, at the 1941 average price paid by the manufacturer for mild steel, 2.8 cents per pound.

B, Low alloy high tensile special structural steel plates, shapes, angles and bar stock as rolled at the mill at the average price paid by the manufacturer for all such low alloy high tensile structural steel in 1941, 3.8 cents per pound.

C, Special tubing and standard pipe used in the manufacture of these units at $.040 per pound, which was the average price paid by the manufacturers in 1941.

D, Labor and overhead, based in all cases upon actual time studies, a "standard cost" involving the actual number of minutes of work (and including "fatigue allowance") required to perform each of the processes of all of the parts, sub-structures and structures and operations to complete the processing and cleaning of these structures. Charged against these minutes (the direct labor) is the overhead for each department. The overhead for the fabricating and assembling department included the electrodes and power cost of arc welding. Since the cost per minute of labor varied in different departments because of the assigning of different items to overhead in different departments the following cost per department in the factory involved in the manufacture of these structures; and the cost therefore used in computing the manufacturing cost of each of these structures in all cost comparisons used in this paper are as follows: (These are the average costs per minute of overhead and labor in 1941):

	Per minute
Steel cutting, shaping and forming department	$0.061
Fabricating and assembling department	.047
Heat treating (and normalizing) department	.117
Machine shop	.084
Cleaning and painting department	.040

Since manufacturing of machinery by the arc welded method is not an uncommon practice today, the numerous details of the exact production of the parts and structures going into this transmission case will not be described here. Suffice it to say that the designers while they drew up the structures were mindful of the elements of good welding practice described earlier in this paper and that the work was done in a modern factory equipped for arc welding manufacture. The parts which made the structures were manufactured from steel plates, shapes, bar stock, and tubing as produced by the steel mill. These parts were sheared, flame cut, rolled, bent or formed according to the requirements of each part in accordance with the most economical method of making them in this particular plant, always with the eye to forming and bending parts wherever possible to improve fit-ups, positioning ease and reduce the number of inches of weld necessary in the structure.

Cost Case Arc Welded—Since the gear case logically formed a separate unit and one which required considerable machining after fabrication; and required that the frame alignment be maintained to a high degree of accuracy after machining, the original case was designed so that by facing the front surfaces and drilling and tapping them, the right and left frame and fuel tank structures could be bolted on to form the major part of the tractor frame and transmission unit.

The fact that the unit was designed for arc welding allowed the designer to use two types of material:

First, a special low alloy high tensile weldable structural steel having a tensile strength of from 80,000 pounds to 90,000 pounds per square inch instead of mild steel of approximately 60,000 pounds per square inch tensile strength, with a reduction in the weight of the main structural portion of the transmission case from 25 to 33 per cent.

Second, the designer used mild steel bearing blocks and bolt blocks

wherever it was advantageous from the standpoint of machinability or economy in the use of materials. Examination of Fig. 24, which is a reproduction of the print used by the shop in setting up and welding the parts and substructures which make up original welded model of the final drive case, shows the several thick bearing blocks which were made of mild steel in order to attain better machinability and to produce the wide bearing and oil seal seat for the main axle bearings and other large bearing seats in the case.

Simplicity of Engineering Prints Reduces Costs—A moment's consideration of the blue print reproduced in Fig. 24 indicates the relatively simple engineering prints which can be used with this method of fabrication.

First, each part of the entire unit can be easily recognized as an individual part by examination of the blue print.

Second, even with the number of dimension on this relatively complex structure and the labelling of the relatively large number of parts and substructures; the print is easily readable. It has a minimum of special sections and other features which consume the draftsman's and engineer's time in drawing and designing, and which add to confusion on the part of workmen in the shop.

Third, the welding symbols used in the welding procedure control in fabricating this structure are included on the print. To one acquainted with the use of arc welding symbols as a means of controls the simplicity of the symbols and the fact that they can be incorporated on as complex a structure as this gear case, indicate that it is practical. The symbols shown are the American Welding Society's welding symbols, to which has been added elements to control the position which the weld will be deposited, the number of passes or beads used in the joint; the type of electrode used; and the machine setting for each pass in the weld was added in later symbols for closer control of the welding process.

Fourth, each of the parts of substructures shown in this print are drawn up separately in the same simplicity, requiring a minimum of dimensions and requiring, for the most part, the very simplest line on the part of the draftsman. No dimensions for fillets at every juncture or change of thickness of section are necessary and no indication of total thickness of section is required such as would be necessary in the case of a cast structure in order to allow the founder to calculate thickness of sections and plan his pattern and pouring procedures to place risers and chill sections in order to get sound castings. The simplicity of the prints which can be used in the arc welding method of fabrication are great savers of time and money in the engineering department as well as in the shop.

Detail of Welded Transmission Case Cost—Table No. II presents a detailed account of the cost of the manufacture of the main transmission case structure of the original welded design, including all of the cost of manufacturing it in the shop up through the normalized and cleaned condition which would be comparable to a clean steel casting, ready for machining. Table No. II does not include any of the machining costs which were involved in the manufacture of this transmission case although it may be observed by examining Fig. 24 that many of these parts have holes already flame cut or punched in them which would correspond in general to the cored holes left in the steel castings.

As shown in Table II, the total cost of fabricating by arc welding this main transmission case of the original design for arc welding was $194.63. The total weight of the structure was 1,097.4 pounds.

Fig. 24. Shop print used for set-up and welding of original model of transmission case.

The cost compared to that of the cost of a similar structure manufactured by the steel casting method is of interest.

Cost of Low Alloy, High Tensile Steel Casting—In the first place an examination of Fig. 24 indicates some problems to the steel foundry which probably could be solved only by some redesign of the case. Attention is called to the thinness of many of the sections of this structure and the fact that there are several closed spaces which would be very difficult to make and to inspect thoroughly by the steel casting method. An example of one of these is the thin section which holds the main bearing block for the axles on the case. Part No. B on that particular structure is made of 1/4-inch special alloy plate. The small spacer, which holds the bearing block out from the main side of the case, is a piece of tubing with a section slightly over 1/4-inch thick. The problem of producing as heavy a bearing block, (which it must be remembered must be of the special high tensile alloy steel if any part of

this case were cast as high tensile alloy steel) would be very difficult because of the change in thickness of sections from very thin to very thick.

Granting that this and several other major difficulties in the production of this unit were overcome and the units were cast from a low alloy, high tensile steel, such a structure could be made. The cost of such a casting has been computed as follows:

A. Based on a publication "Comprehensive Report of Price List of Miscellaneous Castings for the Third Quarter of 1941, beginning July 1, 1941", published by the Steel Founders Society of America, 920 Midland Building, Cleveland, Ohio, the cost of the casting of this transmission case from a low alloy, high tensile structural steel casting, Class A, Grade 2, No. A-148-36, as specified by the A.S.T.M. would be $0.194 per pound in lots over 100. (See alloy price schedule shown in above cited publication opposite page 62). This price is based upon the price for steel castings quoted on page 58 for a tractor-transmission case—crawler type (which is

Table II—Weight and Cost of Transmission Case H-2706 (Original Welded for "Bolt-On" Tank and Fuel Structures, Arc Welded, Normalized and Cleaned, Ready to Machine).

Part	Type of Material	Weight Lbs	Mat Cost	Labor and Over head	Unit Cost	No Used	Total Cost
MAIN STRUCTURE....				77 397	$77 397	1	$77 397
A. Right bull gear housing (structure)				12 810	12 810	1	12 810
Bearing web (sub str)				1.560	1 560	2	3 120
Web plate.	Alloy Plate	115 6	$4 393	1 531	5 924	2	11 848
Bearing block	Alloy Plate	5 1	194	342	.536	2	1 072
Bearing block	Alloy Plate	6 7	255	342	597	2	1 194
Bottom plate	Alloy Plate	29 5	1 121	420	1 541	2	3 082
Outer side plate and bearing (sub. str)				1 607	1 607	2	3 214
Main plate	Alloy Plate	115 6	4 393	1 531	5 924	2	11 848
Upper bearing block	Alloy Plate	12 6	480	397	877	2	1 754
Bearing block support	Alloy Plate	22 9	870	982	1 852	2	3 704
Outer axle bearing (sub. str)				1 166	1 166	2	2 332
Bearing block	1020 Plate	53 0	1 484	647	2 131	2	4 262
Spacer	Alloy Plate	3 5	133	019	152	2	304
B Left bull gear housing structure (Same parts as right bull gear housing with left side set ups Parts shown under right bull gear housing shown under A)				12 810	12 810	1	12.810
C Case center bearing block (sub str)				854	854	2	1 708
Bearing block	1020 Plate	11 3	316	439	665	2	1 330
Center plate	Alloy Plate	74 3	2 823	1 214	4 074	2	8 074
D Main bottom plate	Alloy Plate	99 8	3 792	1 629	5 421	1	5 421
E Main front plate	Alloy Plate	136 0	5 168	1 891	7 059	1	7 059
F Main rear plate	Alloy Plate	133 3	5 054	1 220	6 274	1	6 274
G Right axle housing (Sub structure)	-			1 128	1 128	1	1 128
Web plate	Alloy Plate	3 4	129	018	147	2	294
Side plate	Alloy Plate	4 8	182	018	200	2	400
Web plate	Alloy Plate	6 7	255	019	274	2	548
Bearing block	Alloy Plate	12 6	255	415	670	2	1 340
H Left axle housing sub str (Like G , except left side)	-			1 128	1 128	1	1 128
J. Lower cap	Alloy Plate	4 2	160	019	179	1	179
K Drawbar top block	Alloy Plate	9 4	357	140	497	1	497
L. Case, bottom and drawbar base (sub str)				1 720	1 720	1	1 720
Bottom plate	Alloy Plate	59 0	2 242	1 254	3 496	1	3 496
Lower drawbar block	Alloy Plate	4 8	182	014	196	1	196
M Drawbar gusset	Alloy Plate	1 7	065	317	382	1	.382
N. Gusset (top center plate)	Alloy Plate	3 3	125	019	164	4	.656
O. Case top flange front and rear	Alloy Bar	12 9	490	057	547	2	1 094
P. Inner plate top flange	Alloy Bar	3 6	137	.019	156	2	.312
Q. Outer top flange..	Alloy Bar	8 0	304	018	.322	2	.644
Weight of welds	Weld Metal	143 8					.. .. ..
Total Weight		1,097 4	Total Cost				$194 631

entirely comparable to the wheel tractor transmission case because of the amount of power required to drive the unit) which is classed as an X-303 casting, bearing the price in lots over 100 of $0.174 per pound. An additional 2 cents per pound are added for the alloy as quoted opposite page 62.

Because of the thin sections in this particular transmission case, which are permissible because of the high tensile, low alloy steel used, the weight of such a case made as a steel casting is considered to be 107 per cent of the weight of the welded case. This allows for fillets, risers, and for an additional safety factor in reproducing the very thin sections which can be made by welding and which would be very difficult to make by casting. A cast case comparable to the welded one shown in Fig. 24, the weight and cost of which are shown in Table II, would weigh 1,836.7 pounds, and, purchased at the price of $0.194 per pound, would cost $356.62.

This represents a cost of $161.99 more than the cost of the arc welded structure and indicates a percentage of cost saved by arc welding of 45.4 per cent as well as 7 per cent in weight in the production of this transmission case.

Frame and Fuel Tank Structures—The production of a combined fuel tank and frame structure which bolted on to the transmission case and which supported the motor and gear shifting transmission was a simple matter by arc welding. Fig. 25 shows the print of the right fuel tank and frame structure which was used in manufacturing this structure in the shop. The left tank differed from the right tank shown in Fig. 25 in that it had a fuel sump on the lower side from which the fuel line could draw the last few drops of fuel from that tank. The sump was made by welding a piece of rolled bar stock into a semi-circle and two side plates which closed the arc of the semi-circle to the bottom of the tank in which there had been a hole left to allow the fuel to drain into the pump. Otherwise they were made of the same parts, set up to make a right side and a left side structure.

The thinness of the sections of these members should be observed, noting the fundamental economy of material in this particular structure. It is made as a box section from two plates bent at 90 degrees, arc welded together along the edges of the two resulting angles. They are only 3/16-inch thick, yet have the strength required to support the motor and to withstand the loads required of it and also serve the purpose of oil tight fuel tanks. The spouts are made of a piece of round bar stock which was pre-machined before being welded into the tank structure. The rear bolt plate was made of mild steel for better machinability, since it was faced on the rear and bolt holes drilled in it in order to bolt the tank to the transmission case. A thin walled battery box structure was placed at the rear of the tank on the top side. Note also that the tank has two sets of baffle plates inside of it, made of 1/8-inch mild plate.

From the welding standpoint, this structure was very simple to make. The baffles were welded into one of the side plates as a substructure and then all of the rest of the plates were simply welded together, including the spout which had been pre-machined. Certain parts, labelled "H", in Fig. 25 were small bolt lugs which were welded on after the structure was machined. Since the rear plate was mild steel and the front plate was thick enough so that the effect of welding would not interfere with its machining, this structure did not have to be normalized after welding. Each part of the tank could be inspected as it was manufactured, and after the welding and machining was completed and it was cleaned, it could be tested very readily to be sure it was "fuel-tight" in all of its joints.

Fig. 25. Print for production of right frame and fuel tank structure.

Table III—Weight and Cost of Arc Welded Right Frame and Fuel Tank Structure H-447 (Welded, Cleaned, and Tested to Show Leak Proof).

Part	Type of Material	Weight Lbs.	Mat. Cost	Labor and Over-head	Unit Cost	No. Used	Total Cost
MAIN STRUCTURE				7.128	$7.128	11	$7.128
A. Side plate (sub. str.)				.338	.338	1	.338
Side plate	Alloy Plate	79.0	$3.002	.661	3.663	1	3.663
Baffle strut	1020 Sheet	0.5	.014	.054	.068	2	.136
Baffle	1020 Sheet	2.0	.056	.122	.178	2	.356
B. Lower cap	Alloy Plate	4.9	.186	.020	.206	1	.206
C. Front cap	Alloy Plate	25.4	.965	.029	.994	1	.994
D. Filler neck	1020 Round	3.6	.100	.254	.354	1	.354
E. Battery box side	1020 Plate	10.9	.305	.101	.406	1	.406
G. Strap	Alloy Bar	2.9	.110	.007	.117	1	.117
H. Lug	Alloy Bar	.3	.011	.053	.064	2	.128
J. Battery box side	1020 Plate	13.8	.386	.256	.642	1	.642
K. Rear bolt plate	1020 Plate	40.9	1.145	.018	1.163	1	1.163
L. Tank side	Alloy Plate	73.0	2.774	.720	3.494	1	3.494
M. Step	1020 Round	3.0	.084	.085	.169	1	.169
Weight of welds	Weld Metal	6.4					
Weight		266.6	Total Cost				$19.294

Table IV—Weight and Cost of Arc Welded Left Frame and Fuel Tank Structure H-428 (Welded, Cleaned, and Tested to Show Leak Proof).

Part	Type of Material	Weight Lbs.	Mat. Cost	Labor and Over-head	Unit Cost	No. Used	Total Cost
MAIN STRUCTURE				7.469	$7.469	1	$7.469
A. Side plate (sub. str.)				.338	.338	1	.338
Side plate	Alloy Plate	79.0	$3.002	.661	3.663	1	3.663
Baffle strut	1020 Sheet	0.5	.014	.054	.068	2	.136
Baffle	1020 Sheet	2.0	.056	.122	.178	2	.356
B. Lower cap	Alloy Plate	4.9	.186	.020	.206	1	.206
C. Front cap	Alloy Plate	25.4	.965	.029	.994	1	.994
D. Filler neck	1020 Round	3.6	.100	.254	.354	1	.354
E. Battery box side	1020 Plate	10.9	.305	.121	.426	1	.426
G. Strap	Alloy bar	2.9	.110	.007	.117	1	.117
H. Lug	Alloy Bar	.3	.011	.053	.064	2	.128
J. Battery box side	1020 Plate	13.8	.386	.229	.615	1	.615
K. Rear bolt plate	1020 Plate	40.9	1.145	.018	1.163	1	1.163
L. Tank side	Alloy Plate	73.0	2.774	.720	3.494	1	3.494
M. Step	1020 Round	3.0	.084	.085	.169	1	.169
N. Fuel sump (sub. str.)				1.739	1.739	1	1.739
Bottom plate	Alloy Plate	12.4	.471	.031	.502	1	.502
Side plate	Alloy Plate	4.6	.175	.366	.541	2	1.082
Weight of welds	Weld Metal	7.5					
Weight		284.7	Total Cost				$22.951

Tables III and IV show the details of the cost of manufacturing the right and left fuel tank structures by arc welding, giving the weight and the cost of each structure, completed, through welding, cleaning and testing to show that they are leak proof.

Consultation with several experienced steel foundry men has indicated that the manufacture of the right and left fuel tank structures, shown in Fig. 25, by the steel casting method using low alloy, high tensile steel, exactly like the arc welded structure would be completely impossible. The thinness of the sections of the walls and the placing of ⅛-inch baffles inside of them; and the use of mild steel spouts, a mild steel bolt plate on the rear, and a mild steel battery box structure on the top of the tank would be completely impossible by the steel casting method.

Assuming however for the sake of a comparative cost on a very conservative basis that these units could possibly, by leaving out the baffles or by making them heavier, be made by the steel casting method of low alloy, high tensile steel, the cost of such structures could be computed as follows: Referring to the "Comprehensive Report of Price List of Miscellaneous Castings", published by the Steel Founders Society of America for 1941, page 46, listed as item No. 7213, Class D-6, "Contractors Wagon, crawler or wheel type chassis or rocker beam (box type)", a comparable box structure is described as a Class D-6 casting, which could be purchased in lots of over 100 in the weight range of these fuel tanks at $0.115 per pound. Adding to this $0.115 per pound the 2 cents per pound alloy in order to convert it to the low alloy, high tensile strength material, plus a 10 per cent additional cost, equal to 1.3 cents per pound, for a pressure test to determine that it is leak proof, the total price of such box sections in the cast form would be $0.148 per pound.

Again assuming that the weight of casting is 107 per cent that of the welded structure, the right fuel tank would weigh 284.5 pounds at 14.8 cents per pound. This would amount to a cost of $42.11 as a steel casting. Likewise, the left fuel tank would weigh 307.6 pounds, purchased at 14.8 cents per pound, totalling $45.52. These costs as cast represent a cost of $22.82 more for the cast structure than the welded structure on a right fuel tank frame or a saving by arc welding of 54.2 per cent over the cast production; and $22.57 more for the cast left fuel tank and frame structure, which represents a 49.6 per cent saving by arc welding the structure. It should be borne in mind too, that the cast structures would not be exactly the same design, since the baffles would have to be different and the walls probably thicker.

Belly Guard and Bumper Structure—The belly guard and bumper structure which bolted on to the front of the right and left fuel tank and also bolted (by use of an accessory strip) to the bottom of the right and left fuel tank and frame structures is shown in Fig. 26. A line drawing of the same structure is shown in Fig. 5.

This structure is another example of the simplicity of design which makes use of plates, angles and channels and bar stock, cut to size, bent and shaped to suit the designer's needs and simply welded together. The function of this structure was to protect the under part of the motor and to offer a bumper guard for the front end of the tractor. It was made from low alloy, high tensile steel. The parts which were machined, were all cut of bar stock and pre-machined before welding them together. This allowed for a minimum of handling and machine setting-up in the manufacture of the parts.

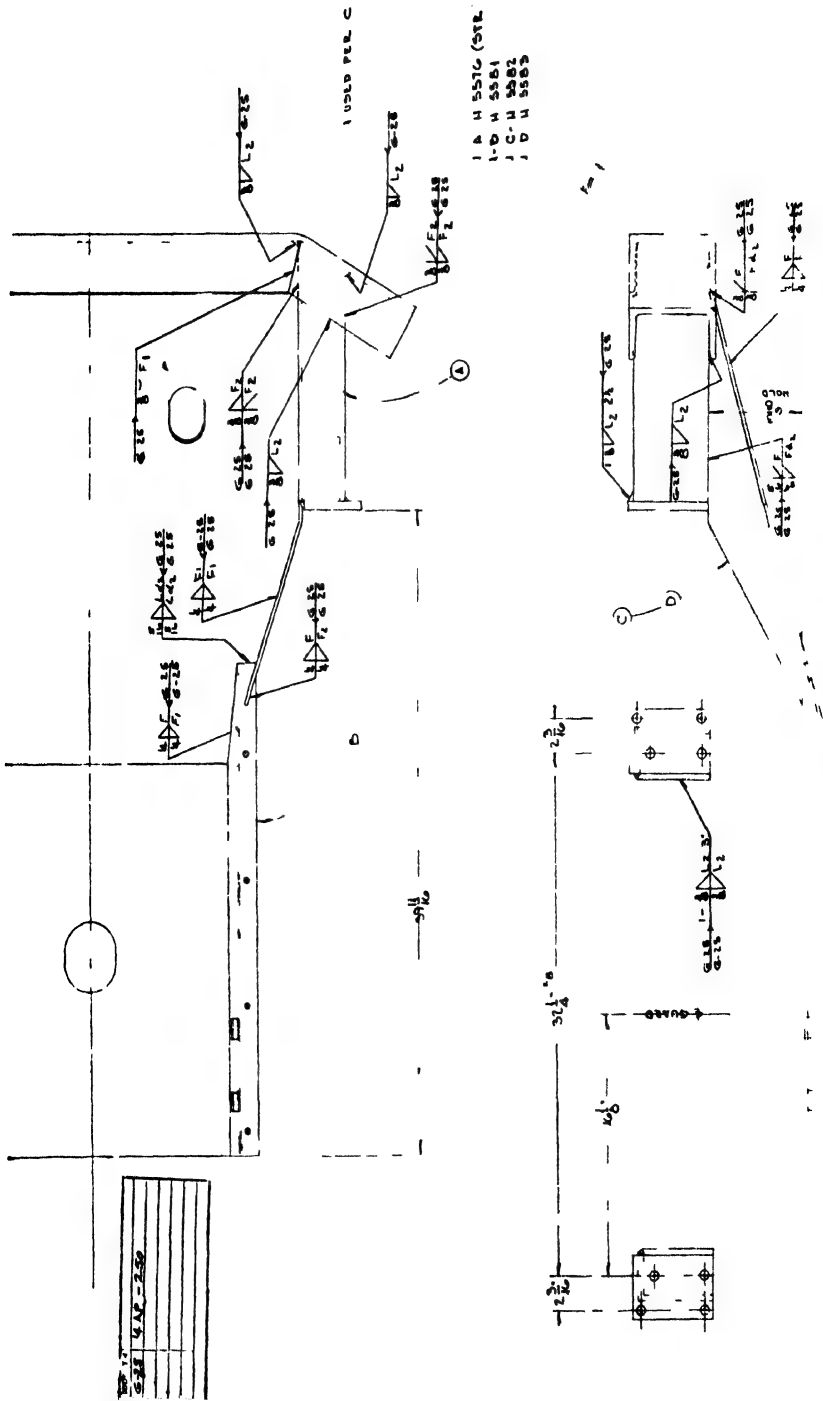



Fig. 28. Shop print for production of belly guard and bumper structure.

Table V shows the cost of this belly guard and bumper structure as fabricated and cleaned but without the machining cost. It weighed 249.4 pounds and cost $17.30. The cost of the individual parts and substructures in the structure are shown in Table V.

Table V—Weight and Cost of Arc Welded Belly Guard and Bumper Structure H-5575 (Welded Complete and Cleaned).

Part	Type of Material	Weight Lbs.	Mat. Cost	Labor and Over-head	Unit Cost	No. Used	Total Cost
MAIN STRUCTURE				2.759	$2.759	1	$2.759
A. Bumper (sub. str.)				2.209	2.209	1	2.209
Channel	Alloy Chan.	59.9	$2.275	.598	2.873	1	2.873
Bolt plate	Alloy Plate	3.2	.122	.128	.250	2	.500
Left beam	Alloy Ang's	24.1	.916	.714	1.630	1	1.630
Right beam	Alloy Ang's	24.1	.916	.714	1.630	1	1.630
B. Belly plate	Alloy Plate	117.4	4.446	.805	5.251	1	5.251
C. Right gusset	Alloy Plate	4.8	.182	.044	.226	1	.226
D. Left gusset	Alloy Plate	4.8	.182	.044	.226	1	.226
Total of weight of welds	Weld Metal	11.1					
Weight		249.4	Total Cost				$17.304

With some redesigning this belly guard and bumper structure could be produced as a steel casting. It is likely that the thin section of the bottom, which, in the welded structure is ¼-inch thick plate, would be difficult to hold to a uniform thickness, in casting. The box sections which support the channel of the bumper would probably be converted to a channel structure in the redesign for casting. Assuming, however, that the casting could be made comparable to the welded structure on the basis that the casting would weigh 107 per cent of the weight of the arc welded structure due to probable thickening of thin sections, and fillets and risers, the cost could be computed for the cast structure as follows: Consulting the "Comprehensive Report of Price List of Miscellaneous Castings", published by the Steel Founders Society of America for 1941, the item listed as D-5, "tractor (crawler type) rock guard", could be considered comparable to this belly guard and bumper structure. The fact that this structure is for a wheel

Table VI—Summary of Analysis of Costs; Arc Welded Compared to Cast Steel; of Completed Structures, Cleaned, Tested and Ready to Machine

Structure	Cost Arc Welded	Cost Cast Steel	Saved by Arc Welding	Percentage Saved by Welding
Transmission case	$194.63	$356.62	$161.99	45.4
Left fuel tank and frame	22.95	45.52	22.57	49.6
Right fuel tank and frame	19.29	42.11	22.82	54.2
Belly guard and bumper	17.30	37.03	19.73	53.3
Total	$254.17	$481.28	$227.11	50.6

type tractor with power comparable to a crawler type tractor would make sufficiently comparable to use the D-5 classification. In lots over 100 within the weight limit of this bumper and belly guard structure, the cost is 11.7 cents per pound, to which must be added the 2 cents per pound special charge for the alloy making a total of 13.7 cents per pound. The casting would weigh 270.3 pounds, and at 13.7 cents per pound would cost $37.03.

Compared to the cost of the arc welded structure there is a saving of $19.73, which would represent 53.3 per cent saving in favor of arc welding. The welded structure would also weigh 7 per cent less.

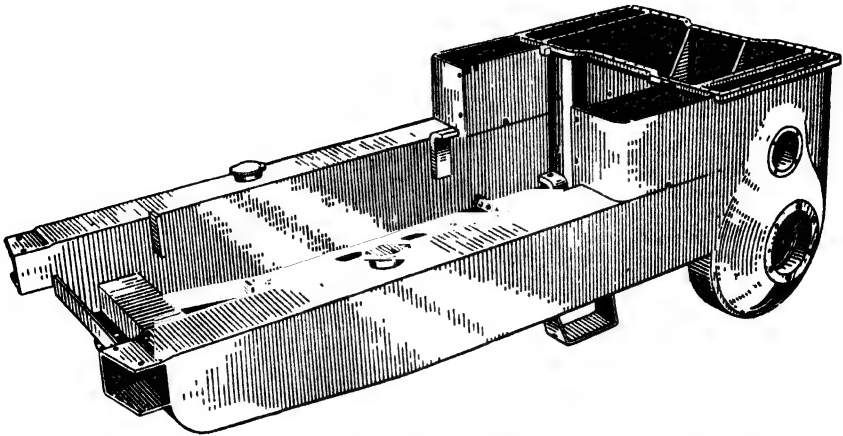



Fig. 27. The improved design resulting from modification of original model.

Cost of Four Main Structures Compared—A summary of the compared costs of the arc welded transmission case, fuel tank and frame structures, and belly guard and bumper structure comparing them to the comparable cast steel structures, is shown in Table IV, which indicates that there is an average saving over the cast steel type of construction by welding of 47.2 per cent on these four main structures. This is on the basis of completely welded structures cleaned, and normalized (if necessary—as indicated for the gear case). This is a very significant statement of the economy of arc welding such structures over any other economical practical method of making such structures.

Cost of Assemblies Compared—While the saving of 50.6 per cent shown in Table VI, in the manufacture of these structures by arc welding over the steel casting cost is very significant, it is well to examine the comparative cost of the two completed frame assemblies, in order to get a comparative evaluation on a thoroughly practical basis, that of the finished assembly ready for use. This gives a comparison of cost of functional design which includes machining cost directly associated with that particular design and the cost of certain purchased parts and accessories and the labor of assembling. All of these costs are very important in the manufacture of a machine and should be included in a comparison of this kind.

Table VII is therefore shown to give the total cost of the unmachined parts which were manufactured in the plant by arc welding, plus the cost of the purchased parts used in the assembly.

Table VII—Cost of Unmachined Transmission Case, "Bolt On" Tanks, and Bumper Assembly, Plus Purchased Parts

Part	Weight of Total Used	Unit Cost	No. Used	Total Cost
C-1677 Capscrew	.4	$0.014	4	$0.056
H-738 Copper washer		.009	4	.036
*Final drive case	1,716.5	194.631	1	194.631
Gasket	.1	0.95	2	1.900
C-1678 Capscrew	5.1	0.017	44	0.748
H-738 Copper washer	.4	0.009	44	0.396
Left fuel tank	287.5	22.951	1	22.951
Motor Hanger	20.8	1.614	1	1.614
C-1540 Lock washer	.1	0.004	4	0.016
C-1524 Nut	.1	0.013	4	0.052
C-1685 Bolt	.3	0.022	4	0.088
Zerk fitting		0.098	1	0.098
Tank cap	2.2	1.305	2	2.610
Tank drain plug (H-6881—not on print)	.1	0.047	2	0.094
Case drain plug (D-1423—not on print)	.2	0.052	3	0.156
Right fuel tank	265.9	19.294	1	19.294
Fuel strainer	.1	0.850	2	1.700
Bumper	252.6	17.304	1	17.304
Filler block	12.8	0.345	2	.690
C-5762 Capscrew	.8	0.023	4	0.092
D-2779 Lockwasher		0.005	8	0.040
D-5639 Allenhead screw	.6	0.093	4	0.372
C-1613 Capscrew	.9	0.014	8	0.112
1540 Lockwasher		0.002	8	0.016
Filler Strip	9.4	0.290	2	.580
Weight	2,576.9	Total Cost		$265.646

Since the machining of the bearing seats, bolt holes and other parts of the main transmission case, except for the facing off and drilling and tapping of the holes for the fuel tanks, would be quite comparable for weldings or castings; and since the cost of machining the case (with the exception above mentioned) does not have a direct bearing upon the cost of the other structures involved in the design, the major machining of the case has been omitted from this study. The difference in the cost of machining the structures as cast or welded is itemized in Table VIII, which shows the cost of machining the structures made from cast steel and those made by arc welding, itemized showing the cost of machining each which had to be machined. Notes explaining the difference in machining costs for the cast structures compared to the same structures made by arc welding, accompany Table VIII.

The fact that many parts in arc welded structures may be machined as parts and then welded into the structures in order to avoid the handling of heavy structures and more difficult machining set up to accomplish the same purpose; and the fact that rolled steel as purchased and welded is sufficiently flat to allow the seating of a capscrew with the lock washer underneath it without additional machining; whereas the castings must be spot-faced, allows a saving of $6.13 in the machining of the welded structures over the machining of the cast structures. This represents a difference of 10.9 per cent in the machining cost as listed for this study.

The completion of the itemized comparison to include the main structures (welded or cast), the purchased parts and accessories, the respective machin-

Table VIII—Difference in Labor and Overhead Cost of Machining Cast Steel Gear Case (For Frame Bolt Base Only) Frame and Fuel Tanks, and Belly Guard and Bumper Structures; and Machining the Same Structures of Welded Design

Structure	Cost* Cast Steel	Cost Arc Welded			
		Pre Machined Part	Machined as Structure	No. Used	Total Cost
Gear case (for tank seating and bolting on only)	$11.567		$11.567	1	$11.567
Left fuel tank	19.759		16.946	1	16.946
Left fuel tank spout		0.520		1	0.520
Right fuel tank	19.159		16.346	1	16.346
Right fuel tank spout		0.520		1	0.520
Motor hanger	1.010	1.010		1	1.010
Bumper and belly guard	4.988			1	.000
Bumper bolt blocks		.366		2	.732
Bumper belly plate		.624		1	.624
Bumper filler block		.496		2	.992
Bumper strips		.548		2	1.096
Total	$56.483				$50.353

Difference in favor of Arc Welded design $6.13
Percentage difference in favor of Arc Welded design 10.9%

Note: Extra cost of machining cast steel structures is due to following items:

A. Tank and frame bolt holes must be spot-faced for capscrews and where rolled steel plate surfaces are square enough as welded. Motor hanger brackets of cast design must be milled square.

B. Tank spouts cannot be pre-fabricated. So must be drilled, bored, tapped in cast tank, frame structures.

C. Bolt plate surfaces of bumper must be milled square to fit tank and frame ends. Pre-drilled bar stock was used in welded structures.

D. Capscrews and bolt holes of bumper must be spot-faced on cast structures.

Table IX—Difference in Cost of Gear Case, Gas Tank and Frame, Bumper, and Accessories, Assembled into Complete Tractor Chasis Frame (Not Including Machining Cost of Main Transmission Case Except for Gas Tank Bolt Bases) Using Cast Steel Structures and Using Arc Welded Structures

Item	Cost Arc Welded	Cost Cast Steel	Saved by Arc Welding	Percentage Saved by Arc Welding
Major structures (Unmachined but cleaned)	$254.17	$481.28	$227.11	47.2
Machining of case for frame base, gas tanks, bumper, belly guard, engine hanger brackets	50.35	56.48	6.13	10.9
Purchased parts and accessories	11.48	11.48		
Assembly	11.04	11.04		
Total	$327.04	$560.28	$233.24	41.6

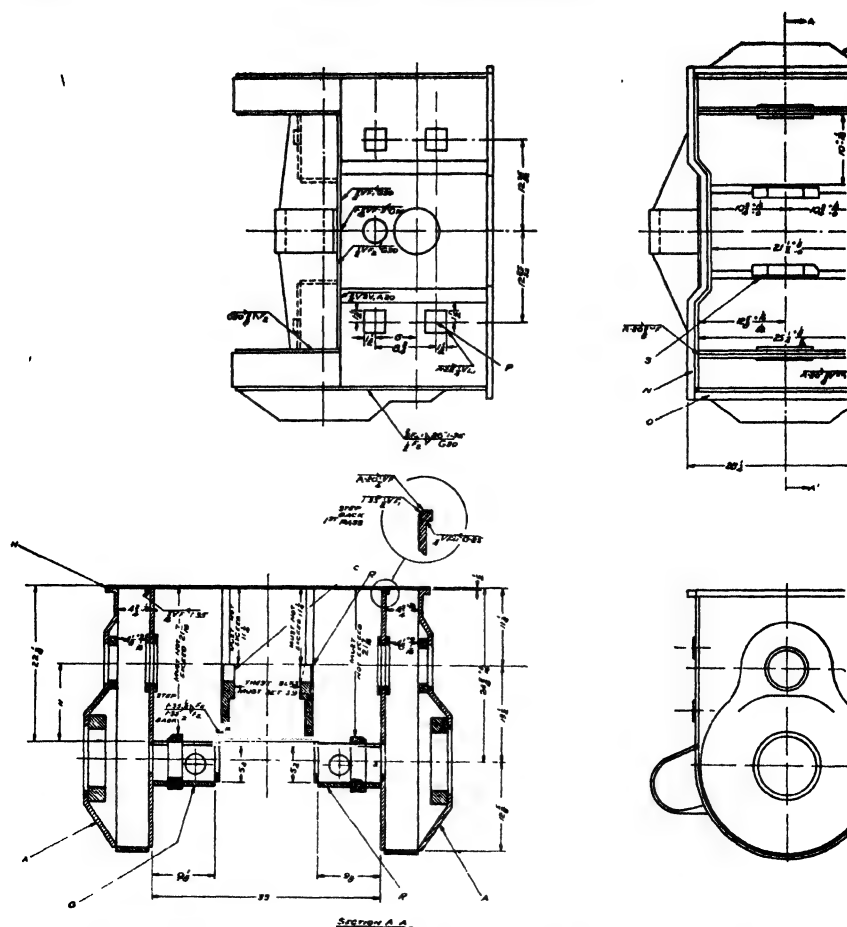
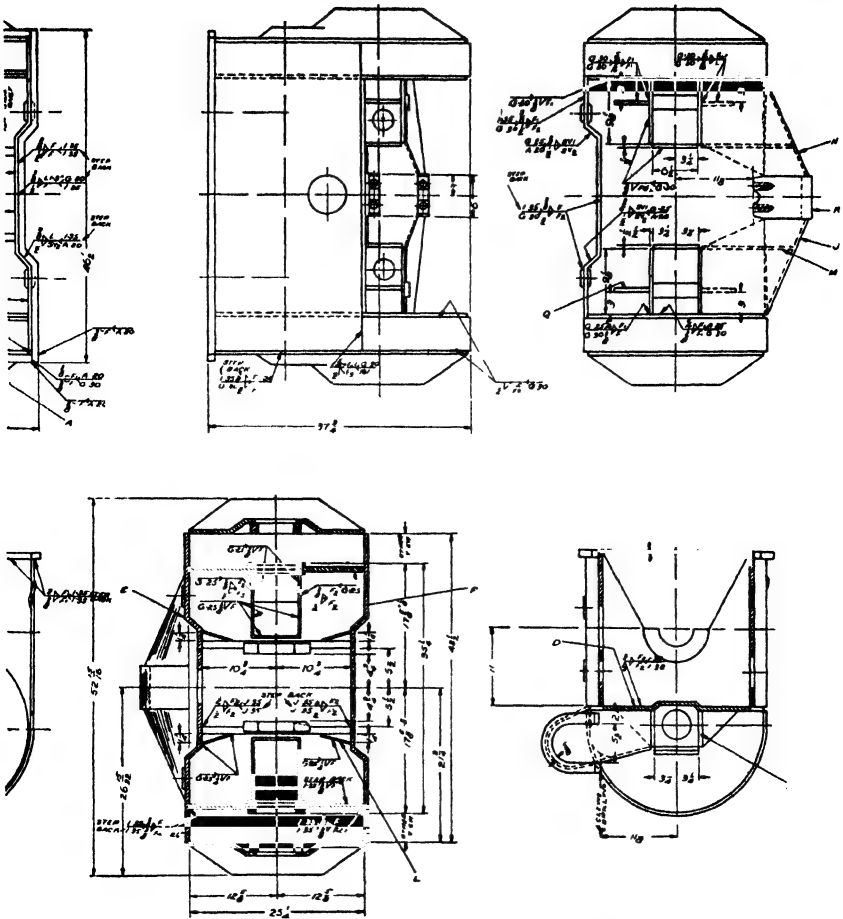



Fig. 28. Print for setting-up for welding the improved model transmission case.

ing costs, and the assembly cost is shown in Table IX. This indicates that in the assembled frames, except with the bumper bolted on, including the main gear case, the fuel tank and frame structures, and the belly guard-and-bumper structure; a total of $233.24 were saved by using the arc welded structures instead of using steel castings. This represents a total of 41.6 per cent difference in favor of the arc welding method of fabrication.

The Second Source of Economy—Before the end of 1940, when 50 or 60 of the original arc welded design of this wheel tractor had been placed in the field, were operating successfully, and receiving a high degree of favor, the second step in developing the most efficient and economical unit was undertaken. This step was the one of refining and improving the original arc welded design.

Although the 41.6 per cent economy over the cast method was significant there were certain improvements which suggested themselves in the manufacture of the original arc welded model; and there were other departures, which if they could be accomplished by the use of the arc welding, would result in considerable saving and an improved unit in the field.

Chief among these was the possibility of arc welding the fuel tanks and frame structures to the main transmission case after the main transmission case had been machined. This would eliminate the cost of the machining on the main case for the fuel tank bases and capscrews, as well as eliminate some material on the tanks and the machining of the tank for seating and drilling the holes for the capscrews.

Naturally, the embarking upon such an ambitious departure from ordinary design involved the question of whether the distortion caused by arc welding the fuel tank and frame structures to the case after it had been machined would distort the case so that the machined parts would not be in proper alignment.

Another change which suggested itself in the experience of manufacturing the original welded model was the possibility of combining the major portion of the belly guard structure with the fuel tank structure if it were possible to weld the fuel tank structure to the main case successfully.

This would allow the installation on the lower front part of the combined fuel tank and belly guard structure of a pull-hook which, according to

experience in the field had been found to be desirable. Since these units are pushed from behind to load them it occasionally was more satisfactory to hook a pulling unit on in front and "snatch-load" them instead of push loading them.

An additional improvement suggested by field operation was that a few more gallons of fuel tank capacity would be helpful. The capacity of the two tanks combined on the original welded units was 51 gallons. Again practice in the field indicated that it might be helpful in operation if a full barrel, amounting to about 53 to 55 gallons could be dumped into the combined fuel tanks of the unit and still have from 5 to 10 additional gallons of capacity so that the unit would run for a while after the barrel-full was used. This would enable the contractor to dump full barrels of fuel into the unit, thereby cutting fuel handling costs in the field.

In addition there had been several possible improvements and economies in the actual manufacture of the structures within the plant which were visualized as being desirable.

The result of these suggested changes which grew out of the experience of manufacturing the original welded unit and trying it out in the field was the design, late in 1940, of the unit shown in Fig. 27. It was found that the welding on of the tank structures to the transmission case after machining was entirely satisfactory from the standpoint of maintaining alignment of the machine bores and bearing surfaces in the transmission case. A minor hand-reaming operation after welding eliminated whatever slight distortion was caused by the welding. This is included in the following cost discussions. The other improvements discussed above were accomplished and will be explained in the description of the individual structures together with the cost of their production by the arc welding method as shown in the following tables and illustrations.

Cost of Improved Welded Design—The changing of the transmission case was a comparatively minor redesign. The improved case is shown in Fig. 28 (a reduced print of the shop drawing for the case) and upon comparison with Fig. 24, (the original model) they will be found to be very much the same. The different type of hitch socket was placed on the bottom of the case in order to facilitate attaching the lower drawbar structure and to make it more substantial. The change in weight and workmanship brought about by this redesign left them quantitatively about the same.

The main improvement was the substituting of one deeply drawn, embossed plate on the outer side to support the main axle bearing block rather than fabricating a lighter support base welded to a heavier, inner side wall main plate as in the original design. This change eliminated several pounds of weight (and its attended cost of material) and markedly reduced the amount of welding in the case. It also considerably improved the streamlined appearance of the case structure. Another change which was made in the case was the use of lighter bearing blocks and the use of mild steel bearing blocks in one or two other places bringing the total percentage of mild steel involved in the case to 16.5 per cent as opposed to 7.4 per cent in the old case. Since the total weight of the improved model case was less than that of the original model, the use of mild steel in greater proportion—maintaining the same functional strength and weight, represented a saving of material cost since mild steel costs 1 cent per pound less than the alloy steel.

Table X shows the itemized cost of the redesigned main transmission case to be $177.84 with a weight of 1660.8 pounds, compared to the original model (welded) costing $194.63 and weighing 1,716.5 pounds.

Table X—Cost of Arc Welded Transmission Case (Redesigned) A-1945, Welded Complete, Normalized, and Cleaned; Ready to Machine

Part	Type of Material	Weight Lbs.	Mat. Cost	Labor and Overhead	Unit Cost	No. Used	Total Cost
MAIN STRUCTURE				$70.085	$70.085	1	$70.085
A. Main bull gear housing structure				9.870	9.870	2	19.740
Outer axle bearing and end plates (sub. str.)				1.819	1.819	2	3.638
Outer side plate	Alloy Plate	155.8	$5.920	1.826	7.746	2	15.492
Pinion bearing block	1020 Plate	9.5	.266	.335	.601	2	1.202
Axle bearing block	1020 Plate	44.8	1.254	.256	1.510	2	3.020
Bottom housing plate	Alloy Plate	28.3	1.075	.378	1.453	2	2.906
Inner housing plate sub-structure				1.354	1.354	2	2.708
Pinion bearing block (outer)	1020 Plate	6.7	.188	.196	.584	2	1.168
Pinion bearing block (inner)	1020 Plate	5.4	.151	.402	.552	2	1.104
Inner web plate	Alloy Plate	113.8	4.324	.989	5.313	2	10.616
Top flange bar	Alloy Plate	3.6	.137	.015	.152	2	.304
C. Case L. center plate (sub. str.)				.761	.761	1	.761
Case center plate	Alloy Plate	71.5	2.717	1.183	3.900	1	3.900
Ring gear bearing block	1020 Plate	10.4	.291	.394	.685	1	.685
D. Case bottom plate	Alloy Plate	94.8	3.602	1.348	4.950	1	4.950
E. Case front plate	Alloy Plate	132.2	5.024	1.617	6.641	1	6.641
F. Case rear plate	Alloy Plate	134.0	5.092	.976	6.068	1	6.068
G. Right axle housing (sub. str.)				2.068	2.068	1	2.068
Housing end plate	1020 Plate	5.4	.151	.055	.205	2	.410
Housing side plate	Alloy Plate	6.7	.255	.031	.281	2	.562
Inner axle bearing block	1020 Plate	21.9	.613	.531	1.144	2	2.288
Housing bottom plate	Alloy Plate	4.4	.167	.055	.222	2	.444
Housing bottom plate	Alloy Plate	2.0	.076	.055	.131	2	.262
Housing side plate	Alloy Plate	6.8	.258	.037	.295	2	.590
H. Right support for draw-bar hitch clevis	1020 Plate	28.5	.798	.261	1.059	1	1.059
J. Drawbar hitch	Alloy Bar	52.1	1.980	.622	2.602	1	2.602
K. Left support for drawbar hitch clevis	1020 Plate	28.5	.798	.261	1.059	1	1.059
L. Gusset	Alloy Plate	3.2	.122	.018	.140	4	.560
M. Hitch support gusset	1020 Plate	5.5	.154	.196	.350	2	.700
N. Front and rear case top flange	Alloy Bar	13.5	.513	.050	.563	2	1.126
O. Case top side flanges	Alloy Bar	7.3	.277	.133	.410	2	.820
P. Case facing blocks	Alloy Plate	.6	.023	.006	.029	4	.116
Q. Axle box gusset	Alloy Plate	1.9	.072	.135	.207	4	.828
R. Left axle housing (sub. str.) like G., right axle housing except left side set-up total for G.				2.008	2.008	1	2.008
S. Case R. center plate (sub. str.)				.761	.761	1	.761
Case center plate	Alloy Plate	71.5	2.717	1.183	3.900	1	3.900
Ring gear bearing block	1020 Plate	10.4	.291	.394	.685	1	.685
Weight of welds	Weld Metal	130.3					
Weight		1,211.3	Total Cost				$177.836

The redesign brought about a noticeable reduction in weight, approximately 100 lbs., and a noticeable reduction in total cost, of approximately $13.00.

The processing of this case after fabrication was entirely comparable to that of the first case with the exception, of course, of the fact that it was not faced on the rear side and prepared for bolting, since the fuel tank structures were welded to it instead of being bolted on.

Design and Cost of the Fuel Tank and Frame Structure—When it was demonstrated that the fuel tank structures could be welded to the transmission case satisfactory, the two fuel tanks-and-frame structures were redesigned, each to be taken out of one single plate 3/16-inch in thickness, bent twice in the form of a "U"-shaped portion of a box and placed upon a main bottom plate which incorporated a part of the function of the belly guard in the original design. This change gave more protection to the lower part of the motor, positively and rigidly spaced the fuel tank and frame structure apart and kept them in alignment and welded solidly to the bottom of the main transmission case.

The new fuel tank and frame design, a working blueprint of which is reproduced (in reduced size) in Fig. 29, embodied also a pull hook with a channel reinforcement on the back side of the main bottom plate of the tank structure and a gusset to the hook which allowed for "snatch-loading." Actually the addition of this pull hook with its reinforcements added 70 pounds to the total weight, representing a 70 pound additional feature in the design which had not been incorporated in the original model. The channel between the fuel and frame boxes increased the rigidity of the whole frame as well as reinforcing the pull hook.

Other refinements are apparent in the improved step bracket used in mounting the tractor made from 3/16-inch plate instead of 1/2-inch round. Further, by punching holes in the main bottom plate (toward the center of the plate from the bottom of the fuel tank) and welding small, pre-machined bolt lugs on it, an oil pan guard plate which extended the whole length of the exposed motor could be bolted (with capscrews) on the bottom of the structure. This made a solid and uniform steel bottom for the whole wheel tractor frame, which fulfilled the function of the belly guard on the original model. Pieces of bar stock were cut, bent, and welded on the front of the fuel tanks to take the place of the bolt plates on the ends of the original model's fuel tanks, so that a very simple bent channel could be bolted to them and form the bumper. These two elements of redesign eliminated the use of the heavier, more expensive and more difficult-to-assemble belly guard and bumper structure, and replaced it with simple structures which will be shown and described.

Pre-machined spouts were used in this structure in the same way that they were in the original; and baffle plates were welded in, (three per tank instead of two) during the fabrication of the structure.

Only a very thin plate was used at the rear end of the tanks, largely to hold them in shape and to insure fuel-tightness. These replaced the bolt plate on the original model's fuel tanks.

This structure has the advantage of combining the principal functions of these structures in the original model into one; making it one uniform, rigid, solid, single structure which, after fabrication and cleaning can be welded on to the completely machined transmission case rather than being bolted on in the assembly line.

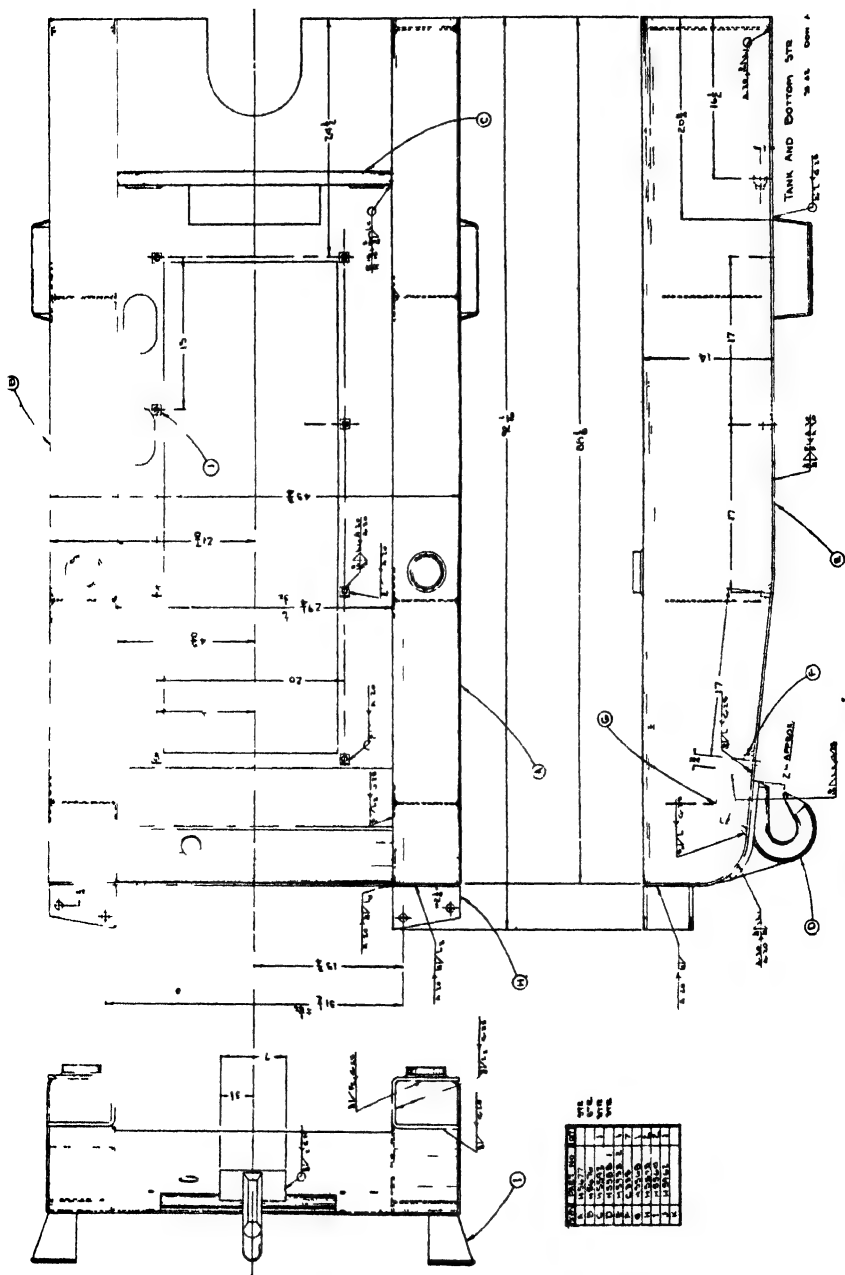
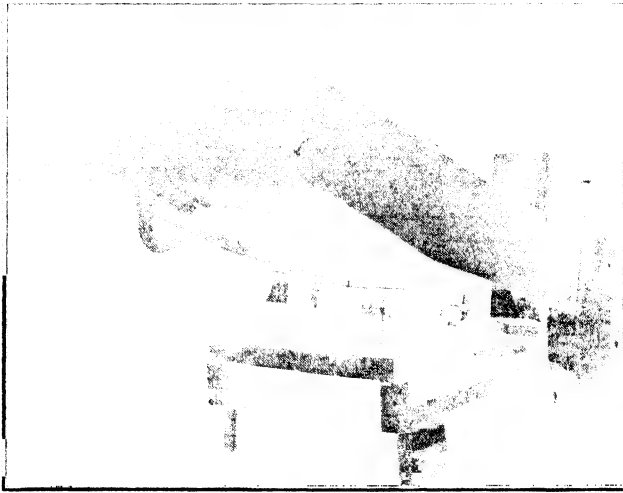



Fig. 30. Lower side of improved model fuel tank and frame structure.

The effectiveness of the use of a single plate for the bottom of the tanks, part of the belly guard and as a stiffener for the whole frame structure is shown in Fig. 30. This shows the appearance of the bottom of the frame assembly without the bumper or without the oil pan. Now compare it to the bottom view of the original design without the bumper and belly guard structure, such as shown in Fig. 31. The more rigid, better protected, and improved streamlining, plus the pull-hook feature of the new design is very apparent when compared to the original welded design.

The cost of fabricating the tank and bottom structure which took the place of the right and left gas tanks in the original design is shown in Table XI. This includes the finished structure, cleaned, and tested for oil tightness.

Fig. 31. Lower side of fuel tank and frame structures with motor assembled.

Table XI—Tank and Bottom Structure H-5674-26 as a Completed Welded Structure, Cleaned and Tested for Oil-Tightness

Part	Type of Material	Weight Lbs.	Mat. Cost	Labor and Over-head	Unit Cost	No. Used	Total Cost
MAIN STRUCTURE				$15.405	$15.405	1	$15.405
A. Left fuel tank (sub. str.)				1.820	1.820	1	1.820
Main plate	Alloy Plate	151.1	$5.742	1.515	7.257	1	7.257
Baffle plate	1020 Sheet	2.6	.073	.024	.097	2	.194
End plate	1020 Plate	6.5	.182	.045	.227	1	.227
Spout	1020 Round	3.6	.100	.254	.354	1	.354
B. Right fuel tank (sub. str.)				1.748	1.748	1	1.748
Main plate	Alloy Plate	151.1	5.742	1.515	7.257	1	7.257
Baffle plate	1020 Sheet	2.6	.073	.024	.097	2	.194
End plate	1020 Plate	6.5	.182	.045	.227	1	.227
Spout	1020 Plate	3.6	.100	.254	.354	1	.354
C. Equalizer pipe (sub. str.)				.767	.767	1	.767
Anchor block	1020 Bar	.3	.008	.018	.026	2	.054
Pipe	Std. Pipe	4.1	.164	.053	.217	1	.217
D. Pull hook (sub. str.)				.738	.738	1	.738
Hook	Alloy Round	12.0	.456	.566	1.022	1	1.022
Base Plate	Alloy Plate	9.0	.342	.054	.396	1	.396
Gusset	Alloy Plate	1.6	.061	.123	.184	1	.184
E. Bottom plate	Alloy Plate	253.6	9.637	1.553	11.190	1	11.190
F. Pan screw lugs	Alloy Bar	.3	.011	.013	.024	7	.168
G. Hook base channel	Alloy Ship Channel	46.6	1.771	.073	1.844	1	1.844
H. Bumper bolt plate	Alloy Plate	8.2	.312	.200	.512	2	1.024
I. Stirrup	1020 Plate	5.4	.151	.086	.237	2	.474
J. Bolt lug	Alloy Bar	.1	.004	.114	.118	1	.118
Weight of welds	Weld Metal	20.3					
Weight		689.1	Total Cost				$53.233

Welding the Fuel Tank and Frame Structure to Main Transmission Case—After the fabrication of the fuel tank, frame, and bottom structure, the next step towards the completion of the wheel tractor frame assembly was the welding of the tank and bottom structure to the machined transmission case.

A working drawing including the part numbers, the structures, dimensions, and the welding control for the welding of this case to the tank and frame structure are shown in Fig. 32.

One thing which is apparent on examination of this print is that several bolt lugs and motor hangar lugs were added to this case and tank structure at this stage of its manufacture which were not incorporated in the original frame and tank structures. These additional hangars give additional freedom and more solid construction in the assembly of the motor and accessories on the finally assembled tractor frame.

Following the elements of good welding procedure and successful welding technique, a fixture is used to position and align the case with the tank and bottom structure. This fixture is shown in operation in Fig. 33.

It not only aligns the case with the fuel tank and frame, but also has aligning and positioning elements on it for the location of the motor hangar brackets and the battery boxes. All of the welding on this structure is done while the parts are in the fixture and may be positioned for the most favorable welding position within the limits of the main structures themselves. The

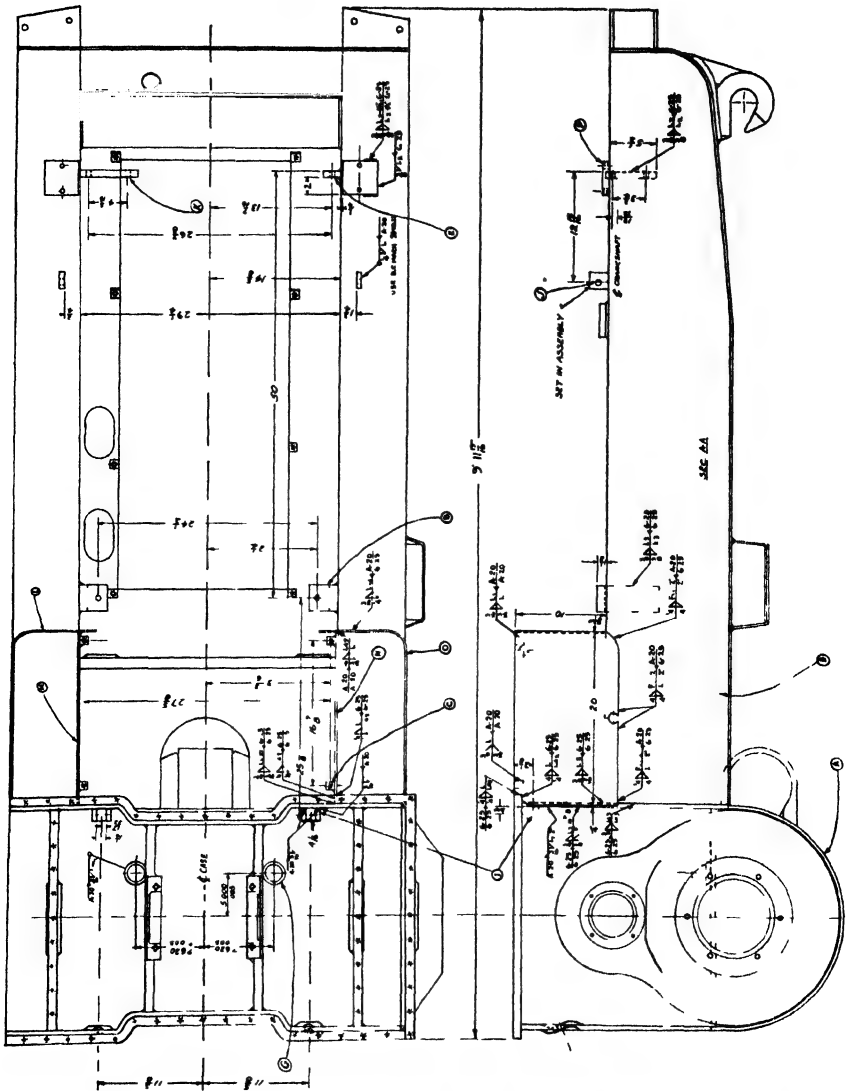



Fig. 32. Shop print for welding fuel tank and frame structure to the transmission case.

fixture turns on one axis only, since the overall length of the case and frame unit is 10 feet.

After welding, these completed frames are removed from the fixtures, the welds are cleaned and painted over and the completed transmission case and frame-fuel-tank assembly are placed on small carts and immediately enter the assembly line shown in Fig. 34.

These structures made ideal fixtures as the basis for the complete assembly of the finished tractor units, and lend themselves ideally to such line assembly processes. The same could be said to a certain degree of the original "bolt on tank and frame" design, but less handling is required on the assembly line and less actual assembly work involved with the new model.

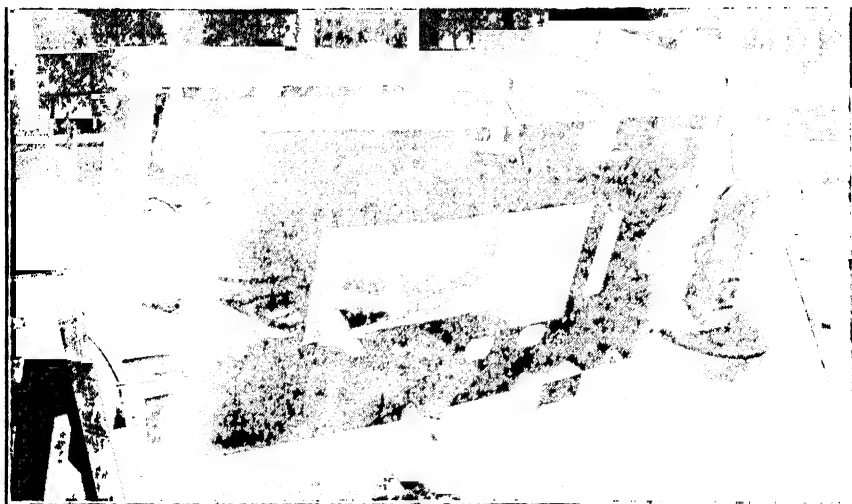



Fig. 33. Fixture allows aligning and positioning case positively and accurately.

Two gaskets, 44 capscrews, and 44 copper washers were eliminated as purchased material in this change, plus the bolt plates on the rear of the original model tank ends of the fuel tank and the surface of the case; plus drilling and tapping of the case and drilling of the fuel tank bolt plates were eliminated, and a simple welding procedure was substituted in the new design.

The cost of the accessory parts involved in the main structures and the welding of the case and tank structure into a unified assembly is shown in Table XII.

Bumper Structure and Oil Pan Guard in New Design—To complete the description of the improved design after the welding of the case and fuel

Fig. 34. Assembly line for welded frame.

Table XII—Cost of Arc Welding Case and Tank Structure, R-2042 to Completed Welding, Including Cleaning

Part	Type of Material	Weight Lbs.	Mat. Cost	Labor and Overhead	Unit Cost	No. Used	Total Cost
MAIN STRUCTURE				19.218	$19.218	1	$19.218
A. Gear case structure (A-1945 after machining cost here quoted is for A-1945, previously shown)		1,660.8		177.836		1	177.836
B. Tank and bottom struc. (shown previously)		710.0		53.233	53.233	1	53.233
C. Bolt / block	Alloy Bar	.3	$0.011	.404	.415	4	1.660
D. Rear motor mount lug	Alloy Bar	7.7	.293	.101	.394	2	.788
E. Front motor mount lug	Alloy Bar	2.7	.103	.044	.147	1	.147
G. Clutch throwout shaft bearing block	1020 Round	2.8	.080	.212	.292	2	.584
I. Brake lug (sub. str.)				.150	.150	2	.300
Base block	Alloy Bar	.8	.030	.206	.236	2	.472
Side lugs	Alloy Bar	.3	.011	.178	.189	4	.756
J. Bolt lugs	Alloy Bar	.6	.022	.043	.067	2	.134
K. Motor support	Alloy Plate	5.1	.194	.221	.415	1	.415
L. Left side (outer) of battery box	1020 Plate	16.4	.459	.160	.619	1	.619
M. Left inner side of battery box	1020 Plate	11.9	.333	.085	.418	1	.418
N. Right inner box of battery box	1020 Plate	11.9	.333	.061	.394	1	.394
O. Right outer side of battery box	1020 Plate	16.4	.459	.160	.619	1	.619
P. Engine hanger filler block	Alloy Bar	3.4	.129	.034	.163	2	.326
Weight of welds	Weld Metal	14.0					
Weight		2465.1	Total Cost				$257.919

tank-frame structure together, the bumper structure shown in Fig. 35 and the oil pan guard shown in Fig. 36 must be considered. The bumper structure, actually uses less channel than the original model's bumper did, and requires only cutting, bending, punching for the holes, and the welding on of two small end caps which are cut from special tubing to complete the structure. This bumper is fastened by four bolts to the end of the fuel tanks and completely takes the place of the somewhat more complicated bumper structure of the original design. The oil pan guard consists of a single plate, sheared to size and bent, with eight small bolt holes punched in it and two larger holes punched or flame cut in them, and a small notch is cut from one side to allow a necessary clearance. This gives better protection to the oil pan and motor than the original model's belly guard, and can be removed easily in the field by removing the eight capscrews which fasten it to the main frame bottom plate.

The cost of fabricating the bumper structure and the oil pan guard are shown in Table XIII and will be added together in a summary of costs in a later table for comparison with the original design.

Table XIII—Cost of Bumper Structure—H-5668-3 as Completed Welding, Cleaned, Ready to Machine

Part	Type of Material	Weight Lbs.	Mat. Cost	Labor and Over-head	Unit Cost	No. Used	Total Cost
MAIN STRUCTURE				.715	$0.715	1	$0.715
A. Main channel	Alloy Ship Channel	59.6	$2.260	1.582	3.842	1	3.842
B. End caps	6" tubing	1.5	.060	.281	.341	2	.682
Weight of welds	Weld Metal	.7					
Total Weight		61.8	Total Cost				5.239

COST OF OIL PAN GUARD H-5952-4B, CLEANED, READY TO MACHINE

SINGLE PLATE	Alloy Plate	74.4	$2.827	.848	$3.675	1	$3.795

Could the Improved Welded Design Be Cast?—An examination of the main transmission case, fuel tank and frame structure shown in Fig. 27 and the parts of which have been described in the immediately foregoing paragraphs indicate that it would be impossible to case from low alloy, high tensile steel as one integral casting, on an economically practical basis, this improved design wheel tractor transmission frame.

No attempt will be made here to predict the cost per pound of such an alloy steel casting as the complete transmission case and frame structure; but it would likely be more than the 19.4¢ per pound which would have to be paid for the gear case structure alone as an alloy steel casting. Since the whole structure would be 10-feet long completed, and would require tests for oil tightness of the fuel tanks, as well as other special inspections, the price schedule per pound would be almost certain to be a higher cost per pound.

Probably the greatest difficulty of all in producing such a casting would be the fact that it would be impossible, on a practical scale, to produce the fuel tanks, which themselves are over six feet long, using a low alloy, high tensile strength steel of 3/16-inch section for the top and sides of the tanks, and 1/4-inch bottom plate throughout being cast integrally with the transmission case and successfully make those castings without leaking, cracking, or being otherwise imperfect. It would be impossible to cast a 1/8-inch baffle plate inside of the tank and to be able to inspect them properly to know for sure that they were satisfactory. Also, it would be impossible to assure the manufacturer that these castings were of sufficient strength in a comparable weight and sound enough to be relied upon within the realm of ordinary economic testing of such castings.

Fig. 35. Simple three-piece bumper structure.

It would be impossible to use the same type of machinery set-up for machining the large case and it would be more expensive from the machining and handling standpoint if it were possible to make such a casting.

One of the biggest disadvantages in casting such a unit as this is that all of the work of making cores, patterns and other foundry processes preparatory to pouring such a casting must precede the actual pouring itself. Once a casting is poured, the whole unit is entirely dependent upon the success of that one operation to produce a sound casting. In the arc welded construction, it is possible to make substructures of from one to several parts; to fabricate them as small units where it is easy to get at the work; to inspect each part as it is completed and to fit the whole together, unifying them into one completed structure on a mass production assembly basis. In this way the parts of many structures are in process at one time, and the spoilage of one part does not seriously impede the progress of the whole order nor cause the scrapping of a completed unit.

Fig. 36. Single plate replacing belly guard.

It is therefore safe to state that the manufacture by the use of the steel casting process of the improved arc welded design in the form in which the arc welded design functions the best, is not an economic possibility. The only way in which a steel casting design can function with any degree of satisfaction for this unit, if the arc welding process were unknown, is in a design comparable to the original arc welded design involving a separate transmission case, two "bolt on" fuel tanks and frames, and a separate bumper and belly guard structure.

Even with such a design the cast units are heavier and more expensive.

Comparative Cost of Completed Frame Assembly—In order to compare the cost of the new design for arc-welded construction with the original design, the cost of the unmachined structures plus the purchased parts involved in the improved design are shown in Table XIV, the details of which are illustrated in Fig. 37.

Table XIV—Weight and Cost of Unmachined Case and Tank, Bumper and Tank Guard Structures and Purchased Accessory Parts for Complete Assembly

Parts	Weight of Parts Used	Unit Cost	No. Used	Total Cost
Final drive				
Case and tank str.	2,485.0	$257.919	1	$257.919
D–1423 Drain plug	.2	0.052	3	0.156
H–6881 Drain plug	.1	0.047	2	0.094
C–1540 Lockwasher	.2	0.002	8	0.016
C–1614 Capscrew	1.0	0.012	8	0.096
Oil tank guard	74.4	3.795	1	3.795
Bumper	62.6	5.239	1	5.239
C–1541 Lockwasher	.3	0.004	8	0.032
C–1525 Nut	.9	0.014	8	0.112
C–1629 Bolt	1.5	0.023	8	0.184
Fuel tank cap	2.2	1.305	2	2.610
Fuel strainer	.1	.850	2	1.700
C–5770 Plug	.1	.031	2	0.062
Weight	2,628.6	Total Cost		$272.015

The items shown in Fig. 37, which represent the improved arc welded design for the wheel tractor frame, transmission assembly are entirely comparable to the items shown in Fig. 27 for the original arc welded design.

The cost of machining of the separate structures and parts which go into this improved design are obviously considerably smaller than in the original welded design. An itemized account of these costs are presented in Table XV, showing the total cost of $8.57 for machining on the improved design as compared to $50.35 for the original design, representing a reduction in machining costs of $41.58.

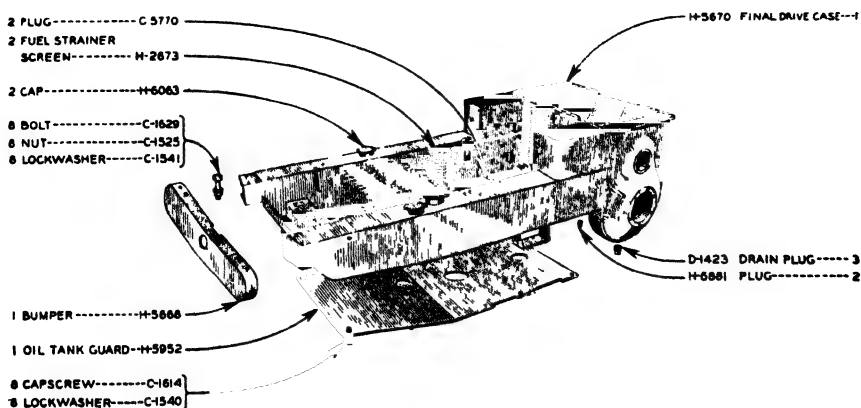



Fig. 37. Structures and parts required for the transmission and frame assembly.

Table XV—Cost of Machining Parts and Structures (Labor and Overhead) for "Welded On" Case and Tank Structure, Bumper and Oil Pan Guard, (Omitting Machining Cost of Main Case and Parts Thereof) Equivalent to "Bolt-On" Case

Part or Structure	Pre-Machined as a Part	Machined as Structure	Number Used	Total Cost
Case and Tank Structure		2.610	1	$2.610
—included parts				
Tank spouts	.052		2	1.004
Left fuel tank	.670		1	.670
Equalizer pipe		.313	1	.313
Main bottom plate	1.305		1	1.305
Pan screw lugs	.037		7	.259
Bumper bolt plate	.278		2	.556
Bolt lug	.087		1	.087
Bolt block	.148		4	.592
Rear motor mount lug	.085		2	.170
Front motor lug	.092		2	.184
Bolt lug	.102		2	.204
Bumper structure			1	.000
Bumper channel	.234		1	.234
Oil pan guard	.482		1	.482
Total Cost				$8.670

This $41.58 is not net saving, but a large portion of it is, as will be demonstrated shortly.

Another portion of the expense of making the completed tractor transmission frame assembly such as shown in Fig. 5, and again a comparable assembly in Fig. 37 is the assembling of the parts. The cost of assembly of the improved design is found to be $1.20 as compared to $11.04 for the old design, a rather significant difference.

A summary of the difference between the cost of the completed and assembled frame made according to the improved design of arc welding, and the original arc welded design is shown in Table XVI.

Table XVI—Summary of Analysis of Cost of Original Design ("Bolt-on-Tanks") and Improved Design with Welded-On Tanks and Frame

Item	Cost First Design	Cost Improved Design
Cost of fabricated major structures and accessory purchased parts (cost of machining structures not included)	265.65	272.02
Cost of machining fabricated parts and structures, not including machining of gear cases (which are comparable and practically unchanged in the redesign)	50.35	8.67
Cost of assembling case, tanks, bumper and oil pan guards to form equivalent "case-tank-frame-bumper-and-guard unit"	11.04	1.20
TOTAL	327.04	281.89
Difference in favor of new design	$45.15	
Percentage difference in favor of new design	13.80%	

This summarizes the items of cost which enter into the completed unit, and shows that there is a net difference of $45.15 in favor of the improved arc welded design over the original arc welded design, or a 13.8% decrease in the manufacturing cost of the completed unit. This does not give a cash value nor compensating cost to the 70 pound pull-hook structure embodied in the improved design and not in the original design, nor the 16 gallons additional fuel tank capacity in the improved design over the original.

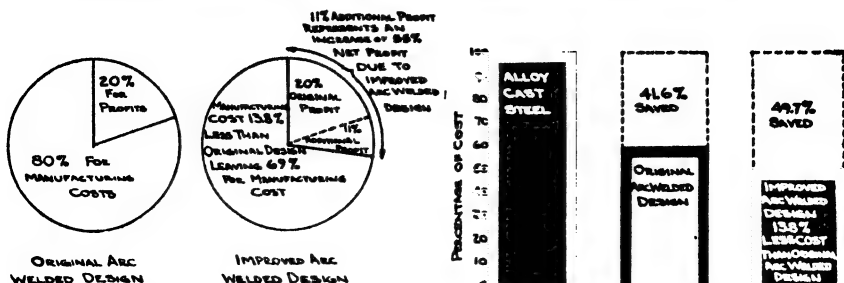



Fig. 38, (left). Graphic proof of fundamental economy of improved design.
Fig. 39, (right). Graphic proof of economy of welded design.

Significance of Saving Due to Improved Design for Arc Welding—The full significance of the 13.8% reduction in the manufacturing cost of the wheel tractor transmission frame structure may be best shown by a statement of the fact that by the time the improvements on the design were made there were almost 100 of the original design tractors in the field. This means that the selling price for these units had been established, that the units had been tried in the field and found to be successful; and that the manufacturer's profit schedule had been established and realized on the production of those 100 or so units of that model. In the light of good business practice it is safe to assume that the original selling price for these units would be set so as to allow the manufacturer a reasonable profit. He then might continue to produce that model, at that reasonable profit until competition forces him to change the design on the price.

However, when he immediately improved his design and placed in production a unit which was superior to the original design embodying certain improvements including such items as the pull-hook on the bottom for snatch-loading, larger capacity fuel tanks, a more rigid and serviceable unit for field service, more streamlined appearance, all for a smaller cost; it places the manufacturer in the admirable position of being able to do one of two things: Either greatly increase his net profit, or deal with competition by reduction in price. This, since the price for such a unit is already established.

Fig. 38 graphically shows the significance of this profit due to redesign. The fact that an established product in the field was redesigned and made for 13.8% less cost, was made superior to the original product, and sold for the same price, allows the manufacturer a margin of 55% more profit than he realized on the original design, (assuming a 20% profit on the original design). The most important part of this situation is that the total number of dollars which were taken from the cost of manufacturing the product by improving design are transferred immediately to the profit side of the ledger without being diverted to sales expense or other phases of industrial cost which had to be incorporated in the setting up of the original price schedule for the original arc welded model.

Fig. 40. Fleet of tractor-scraper units.

It should also be borne in mind that the improvements made possible by the redesign or the refinement of the original design could not have been made without the experience of making the original designed unit first and proving it out in the field on a production basis. This improvement of the original design is therefore one of the most significant sources of profit and economic margin in the manufacturing of arc welded equipment, and it is a step which cannot be taken and completely anticipated in the original design.

Gross Economy of Arc Welding—The fundamental economy of manufacturing wheel tractor transmission case and frame assemblies by the arc welded method rather by other available methods of modern industry is graphically shown in Fig. 39. This shows the comparative cost of manufacturing such units using cast steel structures for the major units of the assembly compared to the original arc welded design as actually manufactured on a production basis involving the production and sale of over 100; and then the cost of manufacturing an equivalent unit by improved original arc welding design, based on production and sale of over 400 of the improved units. The improved design units cost 49.7% less than a similar, but less refined cast steel design.

Aside from the fact that it is a gross saving of 49.7% of the cost using the improved arc welded design over the cost using the cast structures, it should be borne in mind that it is outside of the realm of economic practice to produce the improved welded design unit by casting and it is impossible by the same economic limits, or limits of process to manufacture the original arc welded design to the same strength and weight specification by casting as with the original arc welded design.

Estimated Gross Savings Realized from Economy of Arc Welding—After the first of February, 1941, the improved design for the transmission and frame structure had been proved and mass production of them was begun. In the next twelve months a total of 475 transmission cases and frame units were completed. (428 of these had been assembled and shipped into the field with their scrapers or other accessory equipment).

Bearing in mind the fact that the improved model could not be made within practical economic limits as a steel casting, but could possibly, with some concessions in design, be cast to produce the same functional structures as the original arc welded design; it follows that the difference between the cost of a completely assembled, improved model arc welded case and frame

assembly, and the corresponding assembly made by casting steel as above described is a gross saving in manufacturing of these units. The cost of such a transmission and frame unit using steel castings, including the alloy steel castings; the machining of the frame bolt bases; machining of engine hangars: brackets, etc.; the assembly cost; and purchased parts was shown to be $560.28.

The cost of the improved arc welded design (which included a 70-pound pull-hook structure which was not included in the original welded design nor the cast steel cost estimate) was $281.89.

The use of arc welding therefore allowed the manufacturer a gross saving of $278.39 on each complete transmission case and frame assembly of the improved arc welded design over that of such an assembly using alloy steel castings.

The annual economy may be summarized as follows:

Cost of units of cast alloy steel	$560.28
Cost of arc welded units	281.89
Gross saving/unit by welding	$278.39
Number of each units manufactured during the first year	475
Total gross saving by arc welding— (575 × 278.39) = $160,074.25	

Possible Annual Gross Saving—This wheeled tractor is a "pioneering" unit. In design it is sufficiently unconventional so that it is unlike any product of any existing major industry.

The gross saving of over $160,000 in manufacturing cost by its manufacturer by fabricating it by arc welding is of marked significance because it represents the gross savings realized on the first year's manufacture of the improved design of the tractor.

Production during that year was dependent upon available facilities, and was expanded from a maximum capacity of about 4 per week at the beginning of the year to a capacity of 25 per week by the end of the year.

This expansion was the natural result of the demand of the earth-moving industry for these new type units—a certain proof of their innate economy.

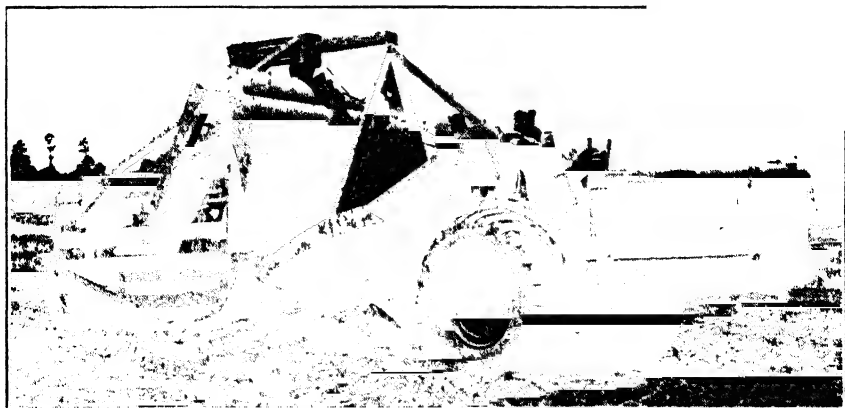



Fig. 41. Wheel-type tractor and scraper dumping and spreading load under positive control.

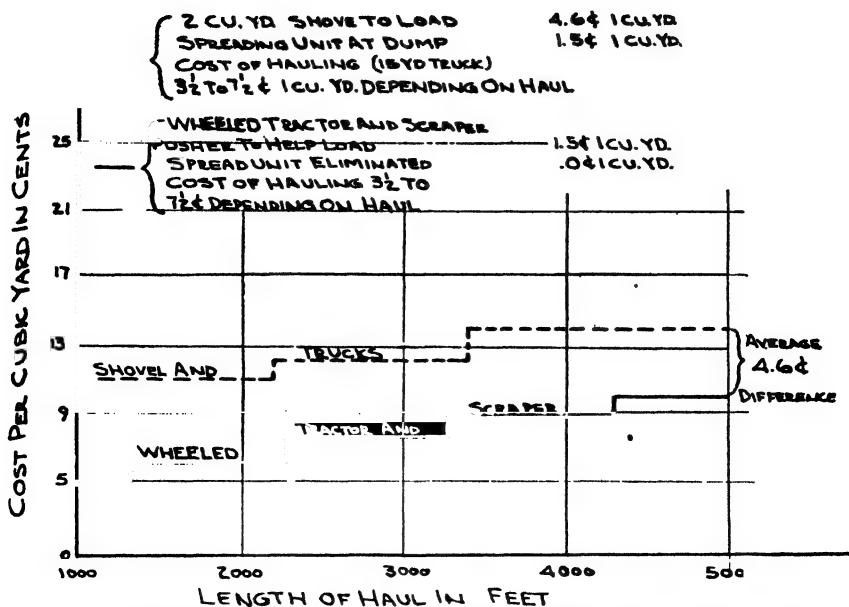



Fig. 42. Comparative cost per cubic yard of earth moved on hauls of 1,000-feet.

Based on a production capacity of 25 units per week, the yearly possible gross savings on the manufacture by arc welding of the transmission and frame structure instead of using alloy steel castings would amount to the following:

25 units/week for 50 weeks = 1250 units.

1250 units @ a saving of $278.39/unit = $347,987.50/year.

It should be pointed out that the transmission case and frame unit was selected as a typical example of the economy made possible to manufacturers of machinery by using high tensile alloy steels and the arc welding method of constructions. The transmission and frame of the wheeled tractor, weighing about 2600 pounds represents only 9 percent of the 29,000 pounds, total weight of the scraper and tractor without tires, motor and other purchased units. A comparable saving on the production of the rest of the unit is realized by this manufacturer, by taking advantage of the same fundamental economies of arc welding low alloy, high tensile steel, so the above quoted gross saving is only a small portion of his actual saving by using the arc welding method of production of his machines.

Social and Economic Development—Field engineering data based on the average performance of some 600 units of this wheel tractor in the field indicate that; as an earthmoving unit powered by a wheel tractor which essentially combines tractor power with truck speed; can load itself with the aid of a pusher, and unload and spread its own material by itself, without the aid of a spreading unit on the dump; this unit embodies certain important economies in the earthmoving field which have not heretofore been possible.

The fact that this unit may be produced by the arc welded method with such splendid economy over any other method which could possibly be used to produce it contributes considerably to this fundamental economy in earthmoving.

Actual field tests on jobs such as shown in Fig. 40 on a typical earth-moving job involving hauls over 1000 feet, using the number of the wheel tractor drawn scraper hauling units which best keep the pusher unit operating, the cost of loading these units is, on the average, 1.5¢ per cubic yard. Varying with the length of haul, the cost per cubic yard of operation and maintenance of the units, the retirement of the original purchase price of the unit and the other direct labor expenses (not including supervision, grade bosses, surveying, etc.,) is from five cents per cubic yard for 1,000 foot haul to approximately 11¢ for a 5,000-foot haul, with the cost rising proportionately for longer hauls. This unit unloads and spreads its own load to the controlled depth and distribution required on the job, requiring no longer to unload and spread, on the average, than a truck. The large pneumatic tires on the scraper and tractor then pack the earth solid, as shown in Fig. 41.

The conventional method and an example of the typical equipment and for doing the same work as described above, would be to use a two-cubic yard capacity power shovel, a fleet of 15-cubic yard capacity trucks, and a spreading unit on the dump. Fig. 42 graphically shows the cost of such a method of earthmoving compared to that using the wheel type tractor and scraper method.

The material is loaded into the trucks by the power shovel, is hauled to the dump where it is dumped (an operation which takes time) and is then distributed by a spreading unit such as a tractor with a Bulldozer mounted on it or a tractor-grader unit.

The cost of these operations total about 4.6¢ per cubic yard for loading and 1.5¢ per cubic yard for spreading and packing. The cost of the haul is found to be no less (on the average) than the cost of using the wheel tractor and scraper, due to the speed and power of the latter (See Fig. 43) so the actual difference in total cost of earthmoving by the wheel tractor and scraper method compared to the shovel, truck and spreader method is (conservatively) 4.6¢ per cubic yard on hauls of over 1,000-feet.

Enough of these wheel-tractor, scraper units are operating in the field at the present time so that the yearly savings to the earthmoving industry on the units actually operating in the field may be estimated conservatively according to the following procedures:

A. Yearly Saving—There are over 600 wheeled-tractor scraper units in the field today, (May 15, 1942) and because of the demand for new

Fig. 43, (left). "Truck speed plus tractor power." Fig. 44, (right). Self-dumping buggy drawn by wheel-type tractor.

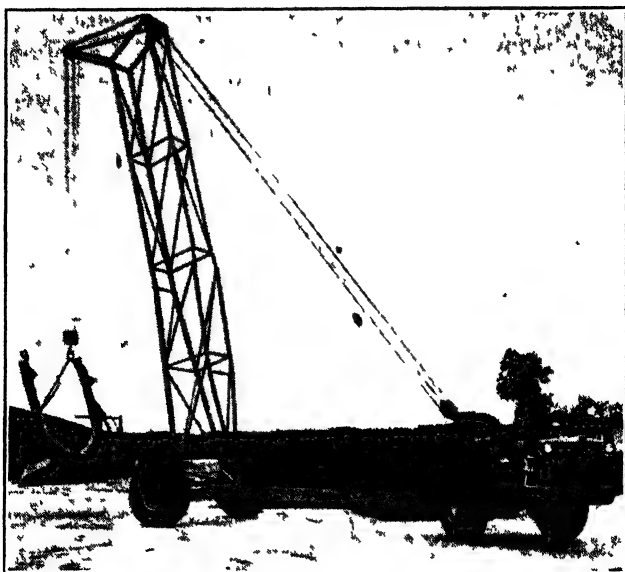



Fig. 45. All welded crane powered by two-wheel tractor.

units it is safe to assume that all are in operation. Experience indicates that the average number of these units per job is 5, and that one tractor pusher unit is used for each such job, (See Fig. 40).

Assuming an average haul of 5,000-feet, these 600 units will average 65-cubic yards of earth per hour, or a total of 39,000-cubic yards per hour.

Conservative estimate of production per unit is 20 hours per day, actual earthmoving for 300 days a year, or:

39,000 × 20 = 780,000-cu. yards per day
780,000 × 300 = 234,000,000-cu. yards per year

Average saving per cubic yard by using wheeled tractor is $ 046, or:

(234,000,000 × $ 046 =) $10,764,000, total annual saving made possible by using arc welded wheeled tractor and scraper units instead of conventional equipment and methods.

What is the potential significance to society as a whole of this annual savings based on machines already operating in the field?

Here are some of the things that could be done with $10,750,000, based on the average bids submitted in 1941 on typical jobs (See "Engineering News Record." Construction cost number—April 23, 1942) such as these: $10,750,000 would:

(A.) Build 450-miles of 22-ft. concrete pavement at current prices; or

(B.) Excavate and oil treat a road 26-ft. wide—450-miles long; or

(C.) Grade, drain and seed 61 typical class 3 airports with 3 landing strips 500-feet wide by 4,000-feet long; or

(D.) Build 12,000-miles of typical 10-ft. high flood protection levee; or

(E.) Build 13 typical 500,000-cu. yd. earth filled dams—with concrete spillways for flood control; or

(F.) Build a complete earth filled dam and power plant such as Anderson Ranch Dam in Idaho—in which there are over 13,000,000 cu. yds. of excavation, a section 1350-ft. long and 330-feet above the riverbed.

Any of these would represent a significant improvement of the nation; and any one of them could have been built with money saved in one year on the earth moved by the 600 arc welded type tractor and scraper units in the field by May, 1942.

B. Difference in Capital Investment to Move 234 Million Cubic Yards of Earth a Year by New and Old Methods—

600 wheeled-tractors and scraper units @ $13,000............=	$ 7,800,000
120 tractor-pusher units @ $8,000............................=	960,000
Total	$ 8,760,000

To move the same 234 million cubic yards of earth 5,000-feet by the older method, using for example 2-cubic-yard capacity power shovels to load, 15-cubic-yard capacity trucks to haul, and one spreading unit (a tractor and Bulldozer) or for each shovel and fleet of trucks. The capital investment represented is as follows:

190	Power shovels (2-cu. yd.) @ $24,000...... =	$ 4,560,000
1140	Trucks (15-cu. yd.) @ $13,150................=	14,991,000
190	Spreading units (tractors & Bulldozer) @ $8,000 ....=	1,520,000
	Total	$21,071,000
	Investment for wheel tractor operation......................	8,760,000
	Difference...............	$12,311,000
	Percent less capital investment in favor of wheel tractor and scraper method...........	58 4%

This reduction in necessary capital investment means (1) that many more construction projects can be bid upon by smaller contractors, and (2) many projects that could not be undertaken by society in the past because of being too expensive may in the future be undertaken because the reduced cost brings them within the limits of economic possibility.

Fig. 46. Fast-moving hauler.

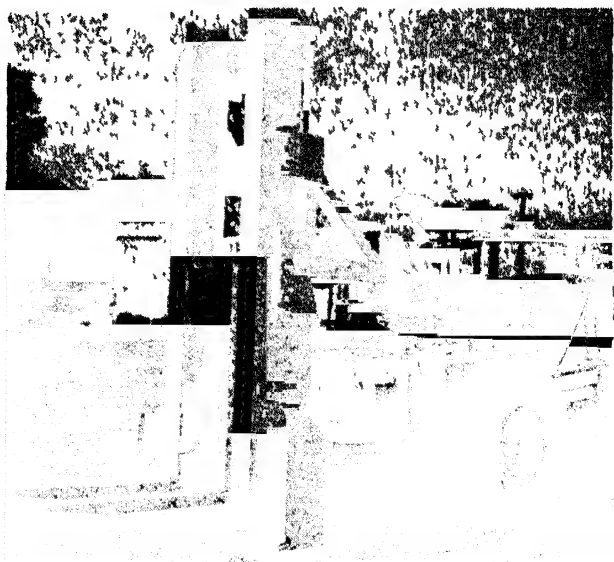



Fig. 47. Lifting and hauling truck having high speed and maneuverability.

C. Difference in Man Power Required to Move 234 Million Cubic Yards of Earth by the New Method and by the Conventional Method—Using 600 wheeled-tractor units and 120 tractor-pusher units to move 234 million cubic yards of earth, 5,000-yards in a year would require 720 men per hour for operation alone, exclusive of supervision and other overhead personnel as follows:

Wheel-tractor and scraper operators	600
Tractor-pusher operators	120
Total men per hour	720

Using power shovels, trucks and spreaders to do the same work, the man power requirements per hour would be as follows:

Power shovel operators	190
Power shovel oilers & helpers	190
Truck drivers	1140
Spreader unit operators	190
Total men per hour	1710
Difference (1710-720) =	990
Percent less manpower per hour in favor of wheel type tractor and scraper method	52.0%

The significance of this possible reduction of man power is simply that the efforts of one man can move a little over twice the amount of earth by the new method than by the old. Since many new jobs will become economically possible, these men will still be used in the earthmoving industry, but more earth will be moved.

A Look Toward the Future—The 600 wheeled tractor and scraper units which have been placed in the earthmoving field since late in 1940 have been found capable of doing the work equal to that of 190 two cubic yard capacity power shovels (and their required truck fleets and spreading units) at a saving of over $10,750,000 per year.

Conservative estimates of the number of power shovels in operation in the field at the present time, and of comparable size to the 190 described, average approximately 10,000 power shovels.

Since in less than two years, new and revolutionary type of arc welded wheeled-tractor and scraper earthmoving units, with a combined capacity equivalent to almost 200 power shovels have been placed in operation at such a significant saving to the industry, it seems reasonable that even greater total savings will be realized by society from the same source of economy in the next few years.

There are other possibilities for the use of the arc welded wheel-tractor in construction work or industrial work than for earthmoving as above outlined. Figs. 44, 45, 46 and 47, illustrate applications which are indicative of a wider application and more extensive use of units which essentially are dependent upon the new wheel-type tractor and the arc welding method of fabrication for their construction, and which are being demanded by the industrial world in increasing numbers.

The essential progress was made in the bold and unconventional departure from the conventional type of wheel-tractor, or crawler-tractor; known in 1940, by the design for fabrication by arc welding of a new powerful wheel-type tractor; and the improvement of the original welded design to an improved welded model which grew out of the experience of building and using the first welded model.

Chapter XXIV—Redesign of Main Frame for Tractor Bullgrader

By GEORGE W. MORK and HOWARD SQUIRES,

Engineer and Manufacturing Engineer, respectively, Bucyrus-Erie Company, South Milwaukee, Wisconsin

George W. Mork

Subject Matter: A redesign by which structural members were butt welded to small high production castings producing a strong, good looking bullgrader main frame at a reduction in cost. The old design required a large number of pieces welded together and large cuts for fittings. Failures occurred due to misalignment. In the new design, strength was added to the longitudinal side members by welding four plates in box form and using thicker plates at the top and bottom to increase the section modulus where it was low previously. Corner sections were castings butt welded to the other members. This resulted in less welding length, fewer members to handle and finish, and a saving of $15.08 on the large frame.

Howard Squires

The progress made in the art of electric welding during the past few years is as responsible for the development of modern earth moving equipment as is the high speed Diesel Engine and its application to the crawler type tractor.

Prominently included in the list of earth moving tractor equipment is the bullgrader, sometimes called an "angle dozer". The industry builds hundreds of them each year and the problems incident with their development have been many, as manufacturing production quantities are large and the competitive situation commercially is keen. All parts of these machines, regardless of size or importance, are being studied continually in order to further reduce cost and increase production.

The purpose of this paper is to prove the possibilities of cost reduction of weldments through the use of composite design embracing structural members joined to small high production machine moulded castings, placed in complex sections through the use of full butt welded joints. For our example we have selected the bullgrader main frame, recently developed by the authors, as one of the finest for which we have been responsible. It represents a just reward in low cost obtained, adaptability to increased production with existing plant facilities, elimination of waste, greater strength because of smooth stress flow, and improved appearance.

At the present time, and for the past few years, our company is and has been building four sizes of bullgraders for tractors of 30, 40, 50 and 70-horsepower. In 1941, total sales of the four sizes was 1319 units. Our production quantities are therefore fairly large for this type of heavy product and small, as well as large, savings are important.

The specific frame which we will describe and analyze in detail is that

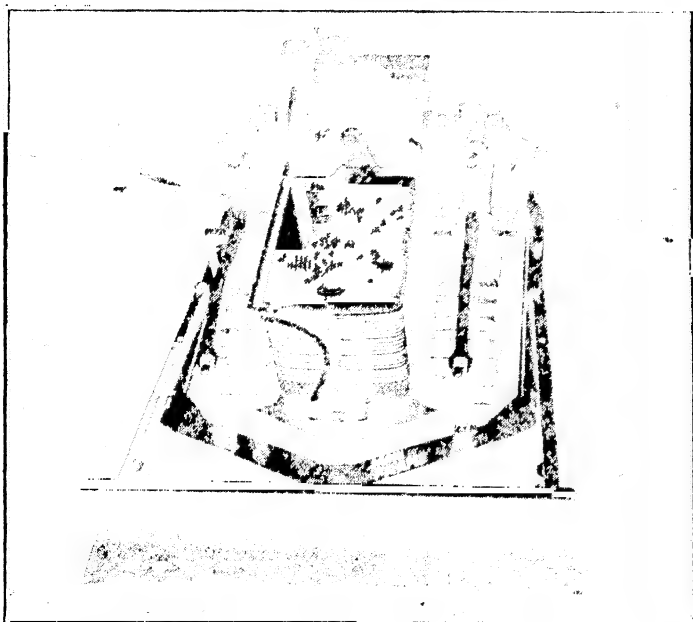



Fig. 1. Bulldozer with digging blade in position for straight work.

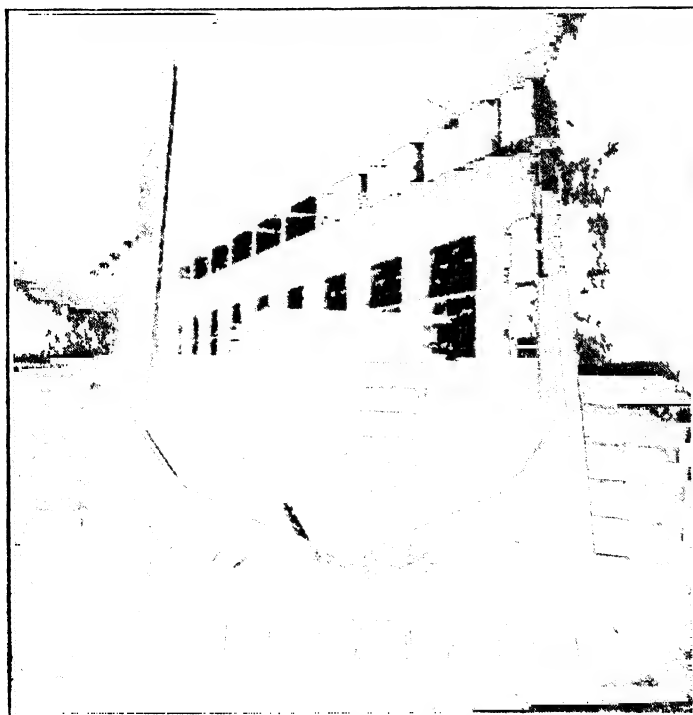



Fig. 2. Frame and blade, old design.

which is used with the largest machine, namely the one designed and built for the 70-horsepower tractor. Because of the many advantages gained we have already gone into production on this size and will soon follow with the others.

In order to obtain a broad picture of its advantages in cost, production, and function we will make a comparison of the new main frame with the one which preceded it.

Fig. 1 illustrates the completed bullgrader and the function of the main frame in the machine. Fig. 1 shows the digging blade in bulldozer position for straight work. The main frame shown in Fig. 1 is of the old design as will be outlined and described later. Fig. 2 gives a clearer view of the frame and how the blade and landside members are attached. This photograph also illustrates the old design.

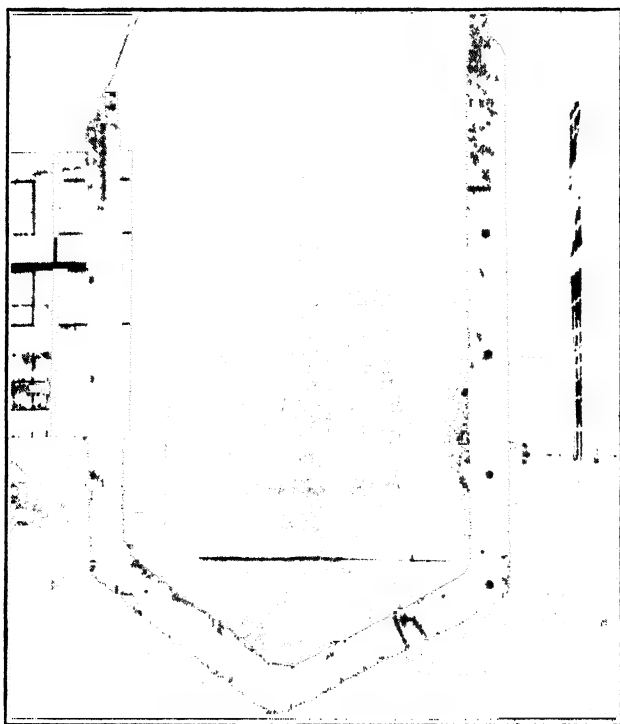



Fig. 3. New design of the frame.

Figs. 3, 4, and 5 of the new design, the subject of this paper, show in good detail the construction. The corner and center castings with their butt welded joints, which will be described in full detail later, are clearly visible in Figs. 4 and 5.

The stress analysis of this member, as is now quite apparent to the reader, is extremely complex and the stresses under maximum loadings are high. Careful design, from its functional standpoint, is therefore quite essential.

With the exception of the center casting the old frame was entirely fabricated. Its cost, although somewhat high as we have now learned, was not

prohibitive. The main members are composed of ship channels welded together at the flanges to form a hollow box beam. In order to obtain sufficient section to withstand vertical bending, reenforcing bars were necessary on both top and bottom. The forward diagonal beam was formed from two plates bent into channels, then welded together to form the box. A complicated unnecessary joint between this beam and the center casting was used because of our early fear of full butt welds. The corner construction was the best we could do with the fabricating facilities available, and, although strong, points of stress concentration were numerous because of overlapping of plates and bars. Under very severe operating conditions a few of these frames broke. These failures all started in the welds at the inner corners between the side and forward beams and the corner plates. The computable stresses under maximum loading conditions at these points are within safe limits so the only remaining conclusion which can be drawn is that stress concentrations in the welds, because of misalignment of the corner plates and beam members, were sufficiently high to cause failure.

When designing the new and now current frame, we succeeded in entirely eliminating overlaps by the simple expedient of making use of small castings at the corners and center. These are formed in such a manner that after fully welded to the main fabricated members the four exterior surfaces are all flush. At this point, please refer to Figs. 3, 4 and 5. Note should be taken that the castings are designed to enter the fabricated beams so as to form back-ups for the butt welds and thus insure 100% welds on all sides. When designing in this manner to obtain smooth stress flow without interruptions, appearance of the finished structure is improved automatically. There are no points of excessive stress concentration in this design as in the old, and consequently the frame is considerably stronger. Please note encircled specification to "grind all butt welds smooth with plate surfaces". This is done to further insure against stress concentration.

The longitudinal side members are built up of four plates, each, welded together at the corners to form the required box. This design permits the obtaining of the larger section modulus required around the horizontal axis by merely selecting thicker top and bottom plates rather than by the addition of

Fig. 4. (left). Close-up showing the welds. Fig. 5. (right). Another close-up of the frame.

plates and their extra welds as in the old design. Referring to Table I, we find that for practically the same overall finished weights we have gained a slight increase (3.7%) in section modulus, 40.8″³ to 42.3″³ in the new over the old design across section X-X and a fairly large increase (17.7%) 34.4″³ to 40.5″³ across Y-Y, the other critical section.

A comparison of rough and finished weights, as taken from Tables I, II and III, is interesting. The amount of scrap steel due to cut-aways, etc. for the old frame is 154-pounds and for the new frame is 36-pounds, or a difference of 118-pounds per frame. For a year's production of 320 frames (see item 9, Table III), a total saving of approximately 38,000 pounds of steel is therefore realized. Though only a small step, it is indeed in the right direction especially during these hazardous days when the problem of waste is so important to us all.

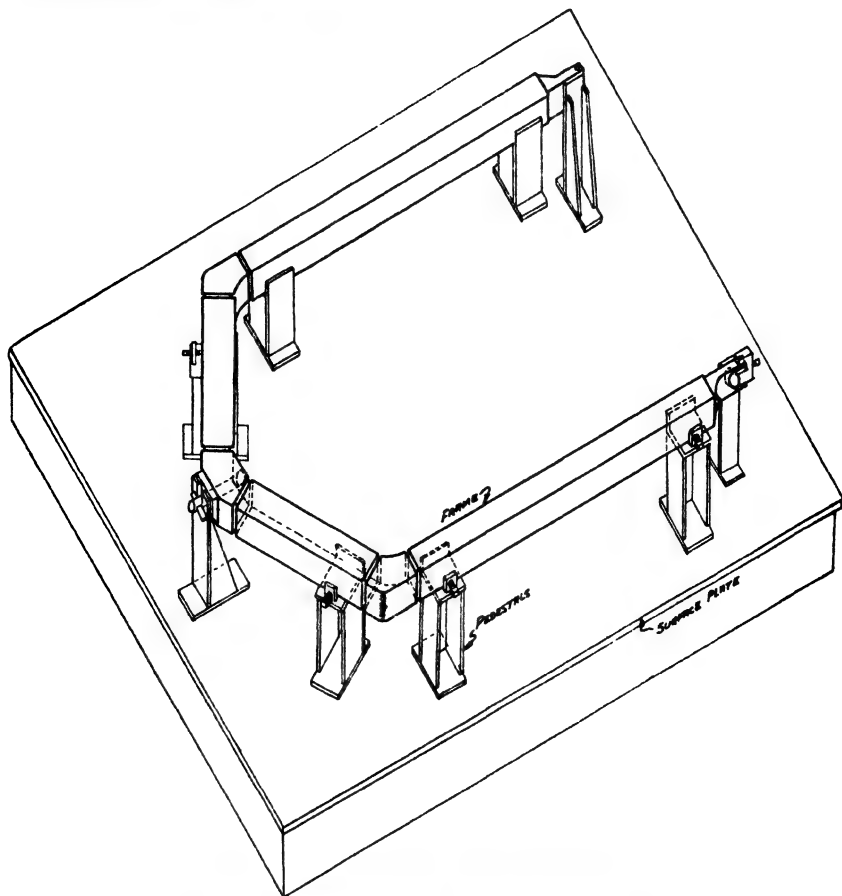



Fig. 6. Sketch showing frame assembly.

Of greater importance are the many advantages which the new frame has over the old from a production standpoint. Not only has the direct labor cost been materially reduced (21.7%), (See Table IV), but the number of pieces which go to make up a complete frame has been reduced from 43 for the old to 31 for the new, a total of 28%, (See Tables I and II). The actual

saving in indirect labor cost which this represents, cannot be computed but when one considers that every operation on each piece is rated and the piece routed for those operations and also that travelers and blueprints must be prepared, one can realize immediately the tremendous importance of this reduction. The indirect cost saving in this instance will actually be considerably more than shown in item 11, Table III.

We have prepared an accurate break-down of the actual direct labor costs of both frames in Table IV. Of interest first in this tabulation is the omission entirely of operations 7 and 8 for the new frame. The planer operation has been reduced 66% because the four plates require no weld preparation, whereas the channels do.

Hand welding has been reduced approximately 13% but this reduction is due primarily to the saving in fit-up rather than to welding as the amount of actual weld deposition is 22.27 pounds for the old frame and 24.58 pounds for the new. We believe, however, that a further saving can be made by reducing the sizes of the butt weld preparations, and experimental work on this point will soon be started.

Automatic welding has also been reduced primarily because of less handling. The footage has been reduced from 95-feet to 90-feet.

Another substantial reduction is in the dressing time, item 9. Butt welds are easier and quicker to dress.

The total saving in hours is the difference between the two totals, 29.693 and 23.223 or 6.470 hours which represents a net direct labor cost saving of $6.46 per frame, or a total works cost saving of $15.08, in spite of the slight increase in material cost, (See Table III). It is interesting to note that the yearly saving amounts to $4820.

A further advantage of our new frame design is its ability to lend itself well to sub-assembly units delivered to the welder. As delivered to the welder, these sub-assemblies consist of the following for the new frame:

2—Trunnion adapter castings
2—Side beams (welded on machine)
2—Corner castings
2—Forward diagonal beams (welded on machine)
2—Clevises
1—Center casting
—
11—Total pieces

The pieces formerly delivered to the welder for the old frame were, as follows:

2—Trunnion adapter castings
2—Side beams (welded on machine)
4—Corner knee brace plates
2—Diaphragm plates
2—Inside bars
2—End plates
2—Clevises
2—Forward diagonal beams (welded on machine)
1—Center casting
—
19—Total pieces

The time saved in the handling of these units is reflected in the welding time as stated previously, inasmuch as the number of units has been reduced from 19 to 11.

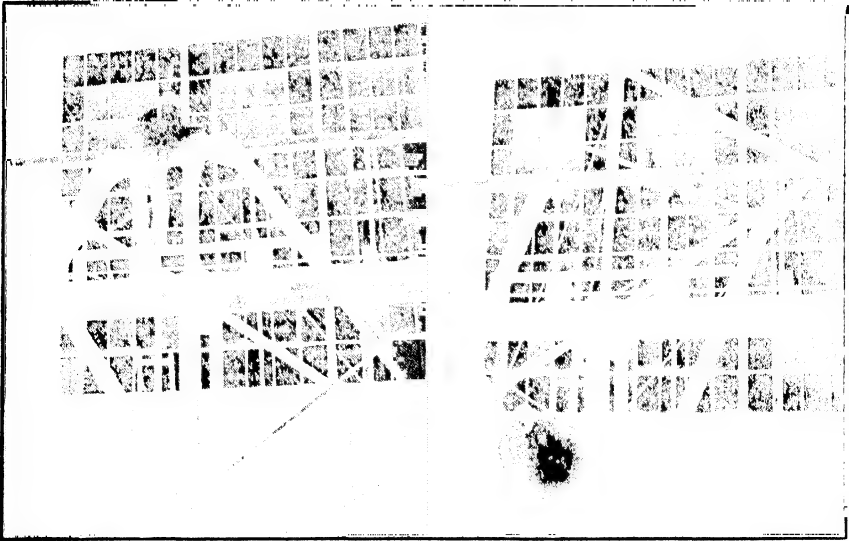



Fig. 7, (left). Arc welding the frame in special fixture. Fig. 8, (right). Fixture rotated for welding.

For assembly of the various units into the completed frame, a large steel surface plate is provided on which removable pedestals are bolted to give proper location of the parts. This allows for a convenient method of handling the several sizes produced and considerably reduces fixture expense as well as simplifies fixture storage.

With the frame assembled in the horizontal position on the plate, (See Fig. 6), the horizontal sections of the butt welds at the corners and center and the fillet welds at the trunnions are laid. The frame is then turned over about the trunnions and the other horizontal welds laid. After these operations the frame is placed into a large revolving fixture attached to the wall, (See Figs. 7 and 8), and the welding completed. All welds are therefore positioned for best welding results. The frames shown in Figs. 7 and 8 are of the old design, but the same fixtures are used just as conveniently for the new frame.

As stated before, this design of frame has already been adopted for the size covered in this paper and will be adopted for the other sizes as soon as possible in order that further savings be realized.

Table I

Material Cost—Old Frame

No. Req'd	Description	Fin. Weight	Rough Weight	Cost
2	Trunnion adapters	43	43	$ 4.60
1	Center casting	121	130	10.15
2	Connecting rod clevises	98	108	5.40
2	Channels	428	432	11.00
2	Channels	390	402	10.25
12	Plates	448	535	17.05
4	Plates	81	85	2.17
2	Plates	10	10	.26
2	Plates	24	25	.64
4	Bars	246	257	7.32
12	Bars	31	35	1.00
4	Bars	12	13	.37
2	Bars	32	36	1.03
	29# Fleetweld	22	29	1.89
	34# Union Melt	34	34	9.87
51	TOTALS	2020#	2174#	$83.00

Wastage—Rough minus finished weight 154#

Table II

Material Cost—New Frame

No. Req'd	Description	Fin. Weight	Rough Weight	Cost
2	Trunnion adapters	64	64	$ 6.15
2	Corner castings	202	206	16.06
1	Center casting	120	129	10.07
2	Connecting rod clevises	50	62	3.10
4	Plates	658	658	16.80
4	Plates	438	438	11.17
12	Bars	30	33	.94
4	Plates	443	443	11.30
	32# Fleetweld	24	32	2.08
	28# Union Melt	28	28	8.12
31	TOTALS	2057#	2093#	$85.79

Wastage—Rough minus finished weight 36#

Table III

Cost and Weight and Other Comparisons

	Old Frame	New Frame
Rough Weight	2174	2093
Finished Weight	2020	2057
Difference—Rough and Finished Weights.	154	36
Section Modulus X–X	40.8"[3]	42.3"[3]
Section Modulus Y–Y	34.4"[3]	40.5"[3]
Total number of pieces in frame	43	31
Manufacturing or Production Quantity	60	60
Total Quantity 1942 Production	0	320
Direct Labor Cost—Lots of 60	$ 29.81	$ 23.34
Indirect Labor Cost—Lots of 60	52.20	40.80
Material Cost	83.00	85.79
Total Works Cost	165.01	149.93

Saving per frame (work cost)	$15.08
Percentage saving	9.15%
Saving per construction of 60 frames	904.80
Saving for 1942 production—320 frames	$4825.60

Table IV

Direct Labor Comparisons

Operation	Rate	Old Frame Hours	Old Frame Cost	New Frame Hours	New Frame Cost
Shear	.85	.675	$ .573	.364	$ .309
Planer	1.04	1.740	1.810	.582	.605
Weld (hand)	1.05	15.100	15.900	13.100	13.750
Weld (automatic)	.91	4.810	4.380	3.880	3.540
Saw	.85	.438	.373	.240	.204
Press Brake (2-Men)	1.79	.403	.722	.288	.516
Hand Burn	.95	.755	.718		
Shaper	.84	.111	.093		
Dress	.91	4.220	3.840	3.400	3.090
Drill	.96	.815	.783	.769	.738
Boring Mill	.98	.626	.614	.600	.588
TOTALS		29.693	$29.806	23.223	$23.340

Percent reduction in Direct Labor Cost

$$\frac{29.806 - 23.340}{29.806} \times 100 = 21.7\%$$

Chapter XXV—High-Temperature Vacuum Fractionating Tower

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Subject Matter: Problems solved by the use of arc welding in the design and construction of a 33-foot diameter vacuum fractionating tower which is one of the largest individual units of equipment ever used in an oil refinery. Welding permitted the use of steel bubble trays instead of cast iron with a saving of 30% in the cost of trays and a considerable saving in weight. Detail strength, size, weight and welding calculations are given for all parts of this unit. The welded construction saved $36,860 as compared to a riveted unit and was erected in two months' less time.

New methods of design and construction by arc welding were used in the erection of one of the largest fractionating towers ever erected at a petroleum refinery. The design and construction of the 33-foot diameter arc welded steel trays, the method of design for vacuum operation and the design and attachment of the vacuum stiffeners are believed to be unique in the refining industry. As noted, the savings in cost, time and materials required were considerable by this method of construction, the last named being most important in the wartime period.

Although the calculations are given in detail, they are essentially of an elementary nature. The article was written several months before actual construction of the vessel began and the photographs included in this publication were submitted later to substantiate the description of the method of construction.

The identity of the oil company building this tower and its location cannot be disclosed at this time. The author nevertheless acknowledges the cooperation of the owner in supplying photographs and authorizing publication of the article. He also expresses his appreciation to his associates in the Petroleum Refinery Division of the Foster Wheeler Corp. for their constructive comments.

Many problems were solved by the use of arc welding in the design and construction of a 33-foot diameter vacuum fractionating tower, one of the largest towers in existence and also one of the largest individual units of equipment ever used in a refinery.

The author's firm was asked by a prominent refining company to design and construct a vacuum stage addition to supplement a crude still installed in 1940. The high rated capacity of this unit, 37,000 barrels per operating day, and the vacuum operation of the fractionating tower resulted in a required diameter of 33-feet. To obtain the different products, mainly different grades of lubricating oils, twelve 33-foot diameter bubble trays were required, in addition to several of smaller diameter in the top and bottom of the tower. The close fractionation requirements of a vacuum tower determined many

features of the bubble tray design, such as number, size and spacing of vapor risers, maximum allowable deflection of supports to insure steady liquid flow and constant level, and spacing between trays.

The process requirements resulted in the arrangement shown in Fig. 1. The following details and problems in connection with this tower were solved by the engineering staff of the firm, and approved by the customer. Amount of electrodes consumed, cost of materials, labor, and production given are based on the firm's welding shop standards.
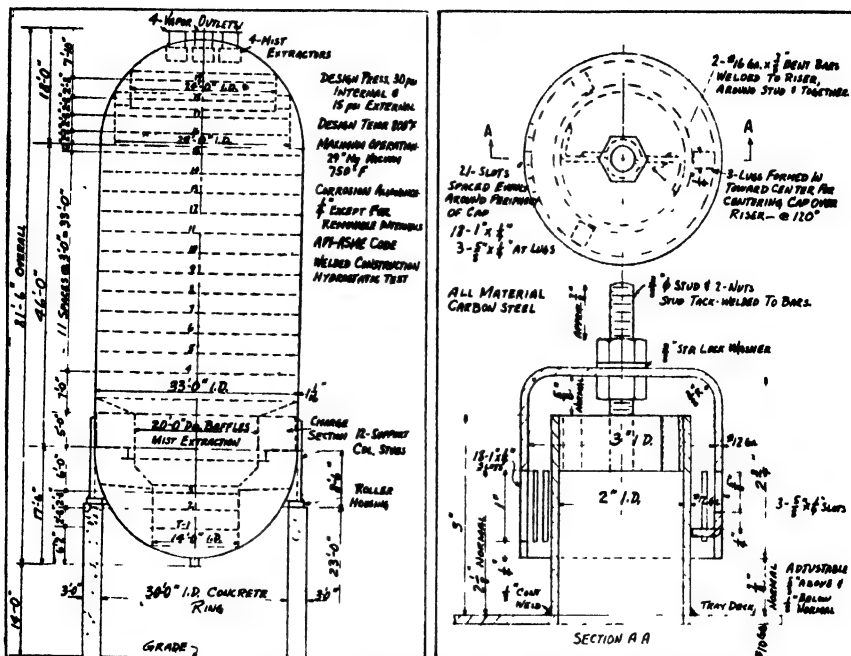
Fig. 1, (left). Vacuum fractionating tower arrangement drawing.
Fig. 2, (right). Fractionating tower bubble cap and riser assembly.

The first and most important problem was the design and construction of the bubble trays. From the arrangement sketch it can be seen that the following is the total tray area:

No. Trays	Diam. Ft.	Area per Tray Sq. Ft.	Total Area Sq. Ft.
3	14	154	462
12	33	855.3	10,264
2	29	660.5	1,321
2	24	452.4	905
Total tray area for tower 12,952 sq. ft.			

This total area shows the importance of designing a tray with the lowest overall cost per square foot, including decking, caps and supports, which would meet the general requirements. These included:

1—Two-inch inside diameter vapor risers with 3-inch I.D. adjustable caps spaced on 4.5-inch equilateral triangular pitch, resulting in 5396 risers per 33-foot diameter tray.

2—Maximum deflection to be 1/16-inch with a liquid load 2-inches above height of weir. With a normal weir height of 3-inches, this meant 5-inches of liquid, of specific gravity not exceeding 1-, or 26-pounds per square foot, to be added to the weight of the tray itself.

3—The maximum length of flow across the tray at any one elevation of the plate is not to exceed 5-feet, requiring 6 levels of 2-inch differences in elevation per tray, or a total of 10-inch difference in elevation across the tray. This was necessary to reduce the hydraulic gradient and insure a steady flow and fixed liquid level. On this depends the uniform passage of the vapors through the slots in the caps, and the corresponding efficiency of fractionation. The adjustable height of caps also helped insure close fractionation and low pressure drop through the tower.

Several types of tray material were considered. For smaller diameter towers, cast iron sections of 3/8-inch minimum thickness are generally used. The weight of these cast trays with a large number of small caps is approximately 60-pounds per square foot, (based on previous experience) which, added to the liquid load, makes the resultant load of 86-pounds per square foot almost impossible to support with a deflection of only 1/16-inch in a span of 33-feet.

A rough layout of the excessive supporting steel was made, and the total cost per cast iron tray estimated as follows:

25,000 lbs. of supporting steel	@ $0.12	=	$3,000
51,300 lbs. of cast iron	@ 0.10	=	5,130
Assembly bolts and gaskets			500
1/12 total pattern costs			400
76,300 lbs. installation of above @ $50 ton			1,900
			$10,930
			(Or $12.80/sq. ft.)

This does not include the additional cubic yards of concrete for foundations due to this excessive weight. Neglecting that, the cost of cast iron trays and supports, therefore, amounts to 12,952-square feet, @ $12.80 = $165,800.

A semi-permanently installed tray of 1/2-inch plate steel was considered and rejected because of the same excessive supporting steel, and differential expansion was feared because of the high operating temperature (750°F.). This installation required 1/8-inch corrosion allowance on all exposed surfaces, and this thickness resulted in a total cost of $13.50 per square foot or more than the cast iron tray.

By making the tray section removable through 14-inch x 30-inch oval manholes installed in the shell at every tray interval, and thus making them quickly replaceable, the corrosion allowance can be omitted and a thinner steel plate used, thus effecting a tremendous saving in weight and materials and making it more practicable to meet the 1/16-inch deflection requirement.

On this basis, a final design meeting all previously mentioned requirements was laid out. Its most important features indicate the importance of arc welding in this type of construction; in fact, no other method would have been very practical, not to mention the considerable savings involved. Fig. 2 shows the method of attaching the adjustable bubble cap and vapor riser to the tray deck, which is of 10-gauge carbon steel plate in accordance with ASTM A-10 specification.

It will be noticed that arc welding is required to properly attach and seal

the vapor riser to the deck plate and that the adjustable cap is supported by a welded attachment of the cap stud and two bent bars to the top of the riser. This was the final approved design. Approximately 0.10 pound of electrode was consumed per riser, making a total of 8240 pounds required for the 82,400 assemblies provided for the tower. The cost per cap assembly, including cap, nipple, stud and two nuts, is approximately $0.50, exclusive of attachment to plate. A firm specializing in this type of fabricated product bid a total $92,600 for all 19 trays, including all deck plates, caps, risers, assembly bolts, trusses and supports except the main beam. This was an average of $7.15 per square foot.

With this basis the following cost per 33-foot diameter tray was calculated as follows:

	Est. Wt. Lbs.	Cost
Tray deck, caps, risers, trusses and minor supports	30,000	$6125
Main supporting beam— (half of built up 2-tray girder)	5,000	600
	35,000	
Install 17.5 tons @ $50 per ton		875
Total cost per tray		$7600
		(Or $8.90/sq.ft.)

This is a saving of $3.90/sq. ft. or 30% less than the cast iron tray. The total saving for the tower is, therefore, 12,952 @ $3.90 = $50,500. The saving in weight is 41,300-lbs. per 33-ft. tray or 43.8-lb./sq. ft. This is a total weight reduction of 567,000 lbs., and is 54% less than the weight of the cast trays.

An even more important consideration is the speeding up of delivery. By saving the time required for making patterns, and for excessive machining which would have been required on the castings, two months of construction time were saved.

Beam Calculations

The problem of 1/16-inch maximum allowable deflection was solved by the use of a built-up welded girder of such depth as to support two of the trays, as shown in Fig. 3.

The beam was bolted to seats welded to the sides of the shell, and to guide lugs welded to correspond with the top of the beam. A 1/8-inch corrosion allowance was added all around to insure that the support would outlast the tray, and that the latter could be replaced without the former. The four 3/4-inch continuous fillet welds 33-ft. long required 220-pounds of welding wire (electrodes) per beam, or 1320-pounds for the six major beams. If riveted construction had been used 4 L's 6-in. x 6-in. x 1-in. would have been required for the flanges instead of two plates 14-in. x 1-in. This amounts to an additional weight of 1800-pounds per beam, or 17.5% excess over the welded beam weight of 10,300-lbs., exclusive of the rivets.

The following calculation indicates selection of beam to meet the deflection requirements and checks the strength of the fillet welds.

With a large-scale layout the tray area supported by the beam was calculated to be 500-sq. ft. or 58.5 percent of the total tray area.

	Pounds
Weight of tray material for 500 sq. ft.	17,500
Weight of liquid @ 26 lbs./sq. ft.	13,000
Weight on one tray	30,500
Weight on two trays	61,000
Est. weight of beam	10,500
Total load	71,500

The beam is supported on 12-in. horizontal stiffeners, leaving unsupported span of 31-ft.

I value needed for $\frac{1}{16}$-inch deflection:

$$I = \frac{5WL^3}{384\ Ed} = \frac{5 \times 71{,}500 \times 372^3}{384 \times 23{,}200{,}000 \times .0625} = 32{,}900 \text{ in.}^4$$

where 23.2×10^6 is the modulus of elasticity of steel at the design temperature of 800 degrees F. Assume beam consisting of a web plate $\frac{3}{4}$-in. x 64-in and two flange plates $\frac{3}{4}$-in x 14-in.

Then per Fig. 3,

I of web plate $\frac{bd^3}{12} = \frac{.75 \times 64^3}{12} = 16{,}384$

I of flange plates $\frac{b(d^3 - d_1^3)}{12} = \frac{13.75(65.75^3 - 64.25^3)}{12} = 21{,}786$

I of beam $= 38{,}170 \text{-in.}^4$

This is, therefore, ample.

Adding $\frac{1}{8}$-in. corrosion allowance to all exposed surfaces of the beam, it requires—

1 web plate	1-in. × 64-in. =	5.33-sq. ft./ft.
2 flange plates	1-in. × 14-in. =	2.33-sq. ft./ft.
		7.66-sq. ft./ft.

Total weight of beam = 7.66 × 32.67-ft. = 2.50-sq. ft. @ 40.8-lb./sq. ft. = 10,200 lbs., which is within the estimated weight.

Maximum bending moment:

$$M = \frac{WL}{8} = \frac{71{,}500 \times 372}{8} = 3{,}325{,}000 \text{ in.-lb.}$$

Unit tensile stress in extreme fibre after corrosion:

$$S = \frac{MC}{I} = \frac{3{,}325{,}000 \times 32.875}{38{,}170} = 2870 \text{ psi}$$

Allowable tensile stress of fillet weld @ 800°F. = 18% of tensile strength (API-ASME Code) = 55,000 × .18 = 9900 psi

Efficiency of fillet welds for structural (Group C) steel = 51% (API-ASME Code)

Maximum allowable working stress of weld = 9900 × .51 = 5050 psi.

This is considerably more than the stress in the beam flange. The net area of two $\frac{3}{4}$-inch fillet welds after $\frac{1}{8}$-inch corrosion, measured across the throat, $= 2(.75 \cos 45° - .125) = .810$ sq. in.

This being greater than the $\frac{3}{4}$-inch web and flange plate, it is sufficient to transfer the stress from one to the other, and prevent flange slippage by

Fig. 3, (left). Detail of main tray beam. Fig. 4, (right). Minor tray support trapezoidal truss.

resisting the maximum horizontal shear at the ends of the beam. Similar calculations were made for all other beams and minor supports.

To provide a seal, 2½-inches × 2½-inches by ⅜-inch circumferential angles were continuously welded to the shell at the level corresponding to its tray section and the latter bolted to it. This attachment could only be made by arc welding. A ¼-inch fillet seal weld was used to allow for ⅛-inch corrosion; the total number of feet being equal to the perimeters of all 19 trays, or 1710-ft. @ 3-lb./ft. = 513-lbs. of electrodes. Every tray section of different level ended with an adjustable weir, bolted to an angle welded to the tray deck. Seal angles were welded to the minor support beams and channels. The trapezoidal support trusses, on which the tray sections were clamped together were of bent 10-gauge plate with lateral bracing bars spot welded to the bottom flanges. (See Fig. 4).

Summarizing, it may be stated that arc welding was used wherever attachment was permanent; only at removable joints were the tray sections joined by clamps, bolts, and gaskets.

Experienced operators claim that this type of tray construction is only locally bent and warped in case of a sudden "shot of water" in the tower; castings would be torn loose and crack and result in a "cascading" of damage to the bottom of the tower. Therefore, less off-stream time would be required for replacement and repairs.

In the event that corrosion is greater than anticipated, the carbon steel tray plates could be replaced after the war with an identical tray of 12 — 14 per cent chrome alloy steel, which would cost approximately $5 per square foot more, but would be corrosion-resistant.

Design of Shell and Heads—The trays being now completely designed, the shell proper and all attachments can be laid out and checked. Because of its size, the shell must be assembled and welded on the refinery site in the field. All parts that can be readily shipped will be prefabricated in the shop and shipped in sections ready for field assembly.

The arrangement sketch states that the design and construction are to be in accordance with the "API-ASME Code for the Design, Construction,

Inspection, and Repair of Unfired Pressure Vessels for Petroleum Liquids and Gases." Paragraph W-403 of this code limits the out-of-roundness of the shell, that is, the difference between the maximum and minimum diameter of any cross-section along the length to ¾-inch. In a vacuum tower the resistance to collapse is inversely proportional to the out-of-roundness, therefore this requirement was reduced to what seems an absolute minimum of ⅝-inch. Another severe tolerance requirement was the alignment of all tray support beams and attachments within 1/16-inch of a level plane perpendicular to the axis of the tower.

The shell thickness was checked for the internal design pressure of 30-pounds per square inch and ¼-inch corrosion allowance in accordance with the following formula in paragraph W-309 of the API-ASME Code:

$$t = \frac{p\,D}{2sE - p} + c$$

where t = thickness of plate in inches,
p = design pressure (internal) psi,
D = inside diameter in inches before corrosion allowance is added.
s = maximum allowable working stress corresponding to the design temperature (psi),
E = efficiency of longitudinal joint,
c = corrosion allowance in inches.

D in inches = 12 × 33 = 396 + 2 × corrosion allowance.
= 396 + 0.5 = 396.5 in. (net or corroded I.D.)

s at 800°F. = 18% of minimum specified range of ultimate tensile strength at atmospheric conditions[1]. ASTM-A-70 flange quality steel, having a minimum of 55,000 psi tensile strength, s = 55,000 × .18 = 9900 psi.

E for flange quality steel (Group B) without a factor for stress-relieving or radiographing (which is impractical because of the field welding) is 78% (Pars. E-318.2 and W-319 of API-ASME Code).

Substituting,

$$t = \frac{30 \times 396.5}{(2 \times 9900 \times .78) - 30} + .25 = 1.0217 \text{ or } 1\tfrac{1}{32}\text{-in.}$$

Thickness of hemispherical heads required to resist an internal pressure of 30 pounds per square inch is calculated by the formula.

$$t = \frac{p\,Dm}{4\,s\,E} + c$$

where Dm = mean diameter of the head flange; the other factors are the same as given in the shell formula above. Assuming t = 1 inch, approximately as in shell, and substituting,

$$t = \frac{30 \times 397}{4 \times 9900 \times .78} + .25$$

$$t = .386 + .25 = .636 \text{ in.}$$

Because of structural loads and stability against wind pressures, and for uniformity of construction, the heads are usually made at least as thick as

[1] See Fig. 1, API-ASME Code for the Design, Construction, Inspection and Repair of Unfired Pressure Vessels for Petroleum Liquids and Gases.

the shell, even though hemispherical heads are subject to only half the hoop stress in the shell. A head of this size could not have been practicably fabricated out of plate thinner than that required for the shell without causing undue distortion during the welding process.

Design for Vacuum Operation—The calculation of the thickness of the plate required to resist external pressure is based on the method employed by the ASME Boiler Code, Section VIII for Unfired Pressure Vessels, except for adjustments for factor of safety and temperature.

Reference is made to Fig. U-19 on page 90 of the 1940 edition of this section of the above code, which is a chart for determining shell thickness of unfired cylindrical pressure vessels subjected to external pressure when constructed of steel with a minimum tensile strength of 55,000-pounds per square inch.

The theoretical and empirical equations involved and the basis of construction of this chart are presented in the article "Vessels Under External Pressure" by D. F. Windenburg, published in the August 1937 issue of "Mechanical Engineering."

The t/D lines on this chart are based on a factor of safety of 5 and the following physical properties of steel at room temperature:

Yield point $S_Y = 27{,}500$ pounds per square inch, in accordance with A.S.T.M. Specifications for 55,000 pounds per square inch minimum tensile strength steels.

Modulus of elasticity $E = 29 \times 10^6$ pounds per square inch.

Poisson's ratio $u = 0.30$.

Where the t/D lines are horizontal in the upper left hand corner of the chart, the formula used to determine the working pressure p is:

$$5\,p = \frac{2\,S_Y\,(t/D)}{1.05} \qquad (1)$$

This is merely the hoop stress formula with a 5 per cent reduction factor applied to short vessels.

The region where the t/D lines are sloping applies to vessels that fail by instability at stresses below the yield point. The following formula is used here to determine the working pressure:

$$5\,p = \frac{2.60\,E\,(t/D)^{5/2}}{(L/D) - 0.45\,(t/D)^{1/2}} \qquad (2)$$

Where L = length of vessel between tangent lines or between centers of circumferential stiffeners measured paralled to the axis, in inches, and D is the outside diameter of shell in inches. A discussion of this formula and its derivation are given in a previous article by D. F. Windenburg and C. Trilling, "Collapse by Instability of Thin Cylindrical Shells Under External Pressure", published in ASME Transactions, Vol. 56, 1934.

In this case, stiffeners were placed on 6-foot centers to correspond to spacing of main tray support beams, therefore L = 72-inches. Assuming thickness is approximately 1-inch per internal pressure design, $D = 396 + 2 \times 1 = 398$-inches.

Then, for $L/D = \frac{72}{398} = .181$, and the maximum external pressure p of 15 pounds per square inch (for vacuum), the corresponding value of t/D on Fig. U-19 is .002.

Therefore $t = .002 \times 398 = .796$-inch.

This figure is then adjusted for the factor of safety of 4 as specified in the API-ASME Code, or $.796 \times \frac{4}{5} = .637$-inch.

This being the required net thickness at room temperature, a final adjustment must be made for the design temperature of 800°F. Since the coordinates of this t/D point on the chart appear on the sloping part of the t/D lines, the adjustment for temperature depends on the corresponding variation in the remaining variable in the equation for that part of the chart, that is, E in equation (2).

The following formula for the modulus of elasticity at temperatures above normal was originally presented in the ASME Transaction for 1928 and is now published in chart form in "Piping Handbook" by Walker and Crocker (McGraw Hill Book Co.):

$$E_t = E_{32}\left[1 - \left(\frac{t-32}{1700}\right)^2\right] \qquad (3)$$

Where E_{32} = E at 32°F., that is, 29×10^6 psi
For 800°F., $E = 23.2 \times 10^6$ psi

Then the corrected value for t at 800°F. is $.637 \times \frac{29.0 \times 10^6}{23.2 \times 10^6} = .796$-in.

Coincidentally, the opposite adjustments for factor of safety and temperature in this case are compensating.

Adding ¼-inch corrosion allowance to the above, the total thickness becomes $.796 + .25 = 1.046$ or $1\frac{1}{16}$-inches.

This is, therefore, the governing shell plate thickness. The heads are made the same for reasons of uniformity in welding and structural and hydrostatic loads, as explained above.

Design for Vacuum Stiffeners—A standard formula for the buckling load of a circular ring under uniform external pressure is $q = \frac{3\,E\,I}{r^3}$ where q is the load per unit circumferential length of the ring and r is the radius of the neutral axis of the ring.

For safety in design the external load is increased 10 per cent.

Calculations and tests show that the combined moment of inertia I of the shell and stiffener was anywhere from 30 per cent to 70 per cent greater than the I of the stiffener only. The lower limit of 30 per cent was conservatively adopted, and a formula derived omitting the effect of the shell from the strength of the stiffener entirely.

Substituting in the above formula I = 1.3 Is, 1.1 (4p) L = q, and D/2 = r, it becomes

$$I_s = \frac{0.140\,D^3pL}{E}$$

Where I_s is the required moment of inertia of the stiffening ring. Substituting the necessary values,

$$I_s = \frac{0.140 \times (398)^3 \times 15 \times 72}{23.2 \times 10^6} = 412\text{-in.}^4$$

In order to avoid stresses due to differential expansion the outstanding member of the stiffener was to be attached to the inside of the shell (it would have been difficult to provide insulation around an external ring) and thus would have the same temperature as the shell to which it is attached. The final design and corresponding calculations are shown in Fig. 5.

Design of Supports—For a difference in temperature of approximately 700°F. between erection and operation, the tower would expand 1¾-inches in diameter, pushing each column at the tangent line out from the center by ⅞-inch. Fixing the base of the columns by anchor bolts would, therefore, create high stresses in the columns and the attachment welding to the shell. Because of the large diameter and total weight of the tower, the overturning moment due to a commonly specified 30-pounds per square foot wind pressure on the projected area was not big enough to overcome the stability of the tower; hence the column bases need not be fixed. It was, therefore, decided to eliminate these thermal stresses by allowing the columns to expand with the tower, on 6-inch diameter steel rollers. The columns were designed on the basis of a complete hydrostatic test, with a total load calculated as follows:

	Approx. Wt., Lbs.
Tower shell, attachments & beams	800,000
Tower trays & minor supports	450,000
Water for hydrostatic test (58,000 cu. ft. @ 62.4)	3,620,000
Insulation	80,000
Piping	20,000
Platforms	10,000
Booster pumps and barometic condenser	150,000
Total weight supported by columns	5,130,000

Because of the rollers, the columns were made as short as possible, in the form of brackets, just long enough to have the head clear the concrete ring. Most of the water load being only temporary, a stress of 15,000-pounds per square inch was used and resulted in a required area of 342-square inches. Using 12 columns, each column stub required 28.5-square inches sectional area. This applies only to its unsupported length, confined to a few inches above the base plate which rests on three 6-inch diameter by 2-foot long rollers.

At high operating temperatures, only a fraction of the liquid weight would be supported (5-inches on trays, or 340,000-pounds) causing the stress to fall below the allowable at 800°F. The design was, therefore, safe for all conditions. The rollers were confined to radial movement in boxes anchored in the concrete foundation ring to prevent side slippage, and keep the center line of the tower stationary. The center line of the column stub bases coincides with the extension of the shell plate, that is, 16-feet, 6-inches from centerline of tower.

Calculations determining the heat transfer from the shell into the support columns indicated that considerable thermal stresses would be set up in the welds attaching the columns to the head plate. In order to keep these stresses down, the following precautions were specified:

1. The temperature difference between the shell and the outside edge of the support is to be maintained as low as possible by means of heating coils fastened to the columns and connected before the tower has been brought up to operating temperature.

2. To facilitate the heat conduction from shell to supports, all plates and brackets are welded through their entire thickness, for their entire length of 12-feet; 4-feet, 6-inches above the tangent line to the shell and 7-feet, 6-inches below the tangent line to the head, providing complete contact, and distributing the stress caused by the transfer of the weight from

shell to supports over as large an area as possible. This also insures greater rigidity of shell and head at those points.

3. The column and roller bearing housings will be completely insulated, and enclosed in a No. 16-gauge steel casing.

4. The attachment welds will be mechanically stress-relieved by peening, that is, tapping with a specified size air hammer to relieve locked-up stresses and close cracks. Thermal stress-relief may cause distortion preventing the careful fitting required by the close tolerances.

Proposed Method of Field Erection—The concrete foundation for the tower was designed for the same loading as the supports, and due to the low soil bearing pressure, piles were required. The top of the concrete ring, 3-feet thick and 33-feet mean diameter is 23-feet above grade. The steel boxes housing the rollers are anchored in the top of the concrete ring so as to permit only radial movement of the rollers and tower. Using an allowable compressive stress of 625-pounds per square inch for concrete, the base plate will be 24-inches x 30-inches.

The heads are shipped to the site in 13 pieces each. The center, or crown piece, is approximately 10-feet in diameter and formed into a spherical dish with a 10-foot, 6-inch radius. The other 12 pieces are in the shape of spherical segments resembling orange peels, with the edge tangential to the shell being 30° of a 33-foot diameter circle, to the middle of which the support column stub is already welded. They are carefully formed with the aid of a template so that when tack welded to the edge of the crown piece they form a 33-foot diameter hemisphere.
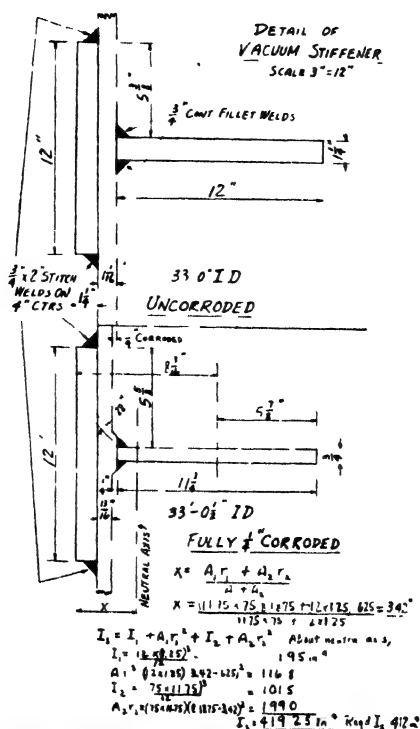
Fig. 5. The final design and corresponding calculations.

The crown piece is lifted into place with a derrick into a carefully built-up crib inside the concrete skirt so that it occupies exactly its final position. Each of the 12 segments is then successively lifted into its proper place and tack welded to the crown piece, with the column stub resting on the rollers. The segments are also tack welded to each other as they fit into place to form the hemisphere. This is a delicate operation requiring extremely skilled workmanship. The top edge must then be perfectly round and horizontal; it is the tangent line, where the straight shell is welded onto the head. The tops of column brackets will be extending 4-feet, 6-inches into the air. They will act as guides for erecting the first course of the shell.

The 46-foot high straight shell will be erected in 6 courses or rings, each of approximately 8-foot height. Each ring will be of four 90° segments rolled in the shop with edges machined and grooved for welding. Each section has a guide lug tack welded to it for the next course. This lug has a hole drilled in it so as to also serve as a lifting lug. It is then lifted into place and tack welded to the section underneath, until the ring is complete; then the seams are completely double butt welded. Thus the total number of feet of 1⅛-inch thick seam welding is calculated as follows:

		Ft.
7—Circular seams 33-ft. dia.	=	728
4—Vertical seams 46-ft. long	=	184
2—Circular seams around crown piece 10-ft. dia.	=	63
24—radial seams in heads @ 21 ft.-long*	=	504
Total lineal feet	=	1479

*Length radial seams $= \frac{1}{2}\frac{(33\pi - 10)}{2} = 21$

At 4.25-pounds per foot this requires 6300-pounds of electrodes. This can be deposited at a rate of about 4-pounds per man-hour using a $\frac{5}{16}$-inch rod, making a total of 1575 man-hours, @ 1.25 = $1970.

The total cost per foot of 1⅛-inch weld is therefore calculated as follows:

Direct labor	$1970
Field equipment, power and supervision 60% of labor	1180
Cost of electrodes, 6300-lbs. @ $0.10	630
Total Cost for 1479-ft.	$3780
	= $2.55 per ft.

This figure would be extremely difficult to duplicate, much less surpass, by any other method such as riveting.

The 8 stiffeners are located so that each ring has at least one, which helps maintain the close out-of-round tolerance. The internal horizontal bar is flame-cut in the shop in 60° segments out of rectangular plates carefully laid out so as to leave a minimum of scrap, and as close to the exact diameter as possible, probably within ¼-inch.

After the first course of shell plates is erected and welded together, the horizontal line for the top of the stiffener bar is laid out by means of a transit to insure being within $\frac{1}{16}$-inch of the same horizontal plane all around, and 1¼-inch x 12-inch triangular shelf brackets welded along this line on approximately 3-foot centers, with ¾-inch continuous fillets. The 60° sections of the ring are then laid on these brackets and butt-welded together to form one continuous ring no more than ¼-inch out of round. The ring is then continuously welded with ¾-inch fillets on both sides to the shell and to the brackets. This tends to draw the shell into the same

close tolerance circle as the ring and insures that no part of the shell will exceed the ⅝-inch out-of-roundness specification.

The outside reinforcing band is then welded on with ¾-inch stitch welds 2-inches x 4-inches, to provide the additional shell rigidity required along that plane. The stiffener rings are spaced 6-feet apart and so located that they also serve as seats for the 5-foot 6-inch deep tray beams, which are bolted to them, additional brackets being welded to ring and shell at those points to transfer the load from the ring to the shell. The total welding per stiffener is thus approximately 480-lineal feet of ¾-inch fillets, or 800-pounds of welding wire. This is a total of 6400-pounds for the 8 stiffeners required, the top and bottom ones not acting as beam supports.

This probably cannot be deposited at a rate exceeding 3-pounds per man-hour, making a total of 2133-man-hours @ $1.25 = $2665. Another method of attachment, such as riveting, would not only cost considerably more, but would not even be feasible unless considerably more steel were added in the form of angles and flanges. Even with additional steel, the tolerance requirement could probably not be met with riveting; welding would appear to be the only practical method of construction.

Strength of Welds—The strength of welds was carefully calculated per the A. P. I.-A. S. M. E. Code. While the ultimate tensile strength of weld metal is about 60,000-pounds per square inch, it is only allowed the same tensile strength of the adjoining steel as given in the A. S. T. M. specifications. The efficiency of fillet welds according to the code for structural steel (Group C) without stress-relieving and X-ray is 51 per cent. The allowable shearing stress is 0.8 of the tensile stress, allowing a stress of 55,000 x .18 x .8 x .51 = 4040-pounds per square inch @ 800°F. for welds perpendicular to the load. For welds parallel to the load, the allowable stress is 75 per cent of that, or 3030-pounds per square inch. The area is measured along the throat of the weld, and ¼-inch corrosion allowance must be deducted from all internal welds on permanent attachments, leaving a net corroded area for ¾-inch fillets of .75 cos 45° — .25 = .28-square inch per lineal inch, or allowable stresses of 1130-pounds per lineal inch and 850-pounds per lineal inch for perpendicular and parallel loads, respectively.

Miscellaneous Internals—As indicated on the arrangement sketch (Fig. 1) below the 4 vapor outlet nozzles in the top head are 4 impingement baffles, or mist extractors, designed to trap any liquid particles that may tend to be drawn off with the overhead vapor. These consist of an intricate circular arrangement of vanes and baffles. Individual vanes and the bottom baffle were of welded construction, but bolted to the welded top support baffle to permit removal and inspection.

The internal shells for the 24-foot and 29-foot diameter trays are ¾-inch plates supported by ¾-inch gusset plates continuously welded to the shell plates and the top head. The main girder supporting the two trays in each section is a 46-inch deep, built-up beam of 1-inch web and 1-inch by 14-inch flange plates, designed and installed as the beam for the 33-foot diameter tray.

The bottom 5-feet of the 33-foot diameter shell is the inlet or charge section. Here the partially vaporized charge comes in through three 16-inch tangential nozzles spaced at 120° intervals in the same horizontal plane. A wear plate ¾-inch by 5-feet is stitch welded 1-inch by 9-inches on both sides all around the circumference on the inside of the shell to prevent erosion and corrosion due to the tangential charge inlets. A large impingement baffle with 24 vane plates ½-inch x 2-feet 6-inches x 5-feet arranged in a 20-foot diameter circle with a conical partition plate ½-inch thick bolted to a ring

at the shell will prevent liquid in the form of mist from going up the tower. This baffle is completely welded except at points of support and attachment to shell where slotted bolt holes provide for expansion due to the high temperature of the baffle.

The shell for the bottom 14-foot diameter trays is constructed similarly to the reduced sections in the top head of ¾-inch plate bolted at points of support and attachment to the bottom head.

Hydrostatic Test—Erection of the tower shell on the foundation is scheduled to start about September 15, 1942, with the tower to be completed about February 15, 1943. The main tray beams are installed as the shell erection progresses in order to add stability to the structure and facilitate access to the interior. The minor tray supports and the tray decks proper are then to be installed before the top head is welded on in order to save time. The common method of installing trays through the manholes requires more time due to restrictions of space and number of men that can be used. After all internals except those in top head are installed, the top head is welded on, all manhole and connection covers are bolted and gasketed properly, and the entire vessel given a hydrostatic test in accordance with the A. P. I.-A. S. M. E. Code.

This requires a test pressure of 1.5 × design pressure, or 45-pounds per square inch measured at the top of the tower, and repeated at subsequent periods throughout the life of the vessel, i.e., until the ¼-inch corrosion allowance has been used up, when the vessel can still withstand such a test. Since it is more convenient to attach and read the gauge at the bottom, the hydrostatic head of liquid or 46 + 33 = 79-feet of water = 35-pounds per square inch is added to the test pressure at the top, giving a gauge reading of 80-pounds per square inch at the bottom.

After the satisfactory completion of the hydrostatic test (showing no leakage) the tower is ready for the finishing touches to be applied before operation is started. The piping will be connected to the nozzles and the insulation applied, together with the welded attachment of steel platforms and access ladders. The unit is expected to be ready for operation about April 1, 1943.

Proportionate Savings Due to Welding—The fabricator's price for furnishing all materials, completely fabricating, field erecting, and testing this tower shell and all internals except trays, as previously described, is $120,000—for an estimated weight of 800,000-pounds, or 15-cents per pound. The total estimated amount of arc welding electrodes for the complete fabrication and erection is approximately 30,000-pounds.

Before the use of arc welding became extensive in the construction of fractionating towers, riveting was the common method of construction. Assuming that this tower could practicably be of complete riveted design and construction and still maintain the rigid tolerance requirements, which is dubious, there would be considerable additional weight of material and cost involved.

The welded efficiency of 78 per cent can presumably be duplicated by a riveted joint, with no change in shell thickness resulting. However, the butt straps, the angle flanges on the stiffeners and beams, the additional clips and gussets required for the complete riveted design would result in additional weight of metal of at least 15 per cent or conservatively, 120,000-pounds. The tremendous number of rivets required for all the attachments on this tower would result in a higher labor cost per unit weight, due to the layout and drilling of holes, shop and field riveting, caulking edges and

joints, and grinding heads of rivets to clear trays. After completion of erection there would probably be repairs necessary to straighten out attachments, meet tolerances, and repair leaks discovered in a hydrostatic test by seal welding.

The relative costs of the tower shell and attachments, exclusive of trays, may be estimated to be distributed as follows:

	Welded Tower			Riveted Tower		
Material	800,000 lbs.	@ .05	$40,000	920,000 lbs.	@ .05	$46,000
Shop prefabrication labor		@ .02	16,000		@ .025	23,000
Shop overhead, 150% of labor			24,000			34,500
Field erection and test		@ .025	20,000		@ .03	27,600
Field equipment and supervision 60% of erection labor			12,000			16,560
Total freight charges		@ .01	8,000		@ .01	9,200
			$120,000			$156,860
		=	$0.15/lb.		=	$0.17/lb.

The savings of $36,860 = 23.5 per cent of the cost of the riveted tower, or 30.7 per cent of the welded tower. Tray savings have already been stated above.

Total Savings by the Company and Industry—The author's company, one of the major engineering firms engaged in the design and construction of refineries for war products such as toluene and high octane aviation gasoline is now constructing refineries with welded towers and tanks weighing approximately 20,000-tons at $300 per ton = $6,000,000 investment in welded pressure vessels. On the basis of the above comparison, the saving is 30.7 per cent over riveted construction, or $1,840,000 total annual savings by the company in this phase of its war effort.

The total annual gross savings throughout the petroleum refinery and allied chemical industry is difficult to estimate; but considering that the total value of such construction in the present war effort is in the order of $1,500,000,000, it appears that the total value of welded vessels is approximately $200,000,000, and that a savings in the order of $60,000,000 is a conservative estimate.

In addition to the above monetary savings, the use of arc welding results in a number of other advantages. The service life of welded towers is lengthened by welded replacement of corroded internal parts, which could not easily be replaced any other way due to limited means of accessibility.

Greater efficiency of fractionation, and therefore more useful products, is obtained by welding, since any other method would probably not meet the tolerance specifications.

The savings of 15 per cent in weight of metal required indicates a greater efficiency in the use of our available resources and materials toward obtaining the desired result, and at this time is of supreme importance in our war effort. This economy of materials also leads to economy of time in construction; the 15 per cent extra weight would presumably take at least 15 per cent more time for erection. Actually, the saving in time, and the consequent start of production of the lube oils, is much greater than that, since riveted construction involves the handling of many more small parts, which by welding can be more efficiently prefabricated in the shop.

The fact that riveted construction in oil refinery equipment has become almost obsolete in the last 10 years by the use of arc welding is a certain sign that industry is quick to recognize and take advantage of these overall improvements.

Chapter XXVI—Batching Scraper for Crude Oil Pipe Lines

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Robert M. Carter

Subject Matter: A batching scraper for crude oil pipe lines designed for arc welded construction. It is necessary that the refinery know what grade of crude oil is being supplied and when delivery from different areas is made through the same pipe. It is important that the two batches be properly separated with a minimum of mixing. Previous to the present design, pipe line scrapers were sent down the line for this purpose. The disadvantages of this were: inefficiency in separating batches, high maintenance cost as a result of wear and breakage due to jamming. This unit was replaced by a simple batching scraper which consisted mainly of two rubber discs mounted on a central body behind a guiding conical-shaped framework. Not only did this unit improve separation, it also reduced the cost and maintenance and improved pipe cleaning. A considerable saving because of less repairs and less waste oil is expected.

The arc welding process is extensively used by pipe-line companies for constructing and maintaining pipe lines and fabricating manifold piping systems. Interest in the larger projects often diverts attention from the benefits to be derived from the use of arc welding in the production of specialized tools and equipment, which may effect better economies in other phases of the companies' operations. It is hoped that the experience related in this paper will focus greater attention to the possibilities of this application of arc welding.

In the early development of overland pipe-line systems for transporting crude oil, oil from various producing areas was mixed together in the main trunk-line system and delivered to the refineries in conglomerate streams. Present refinery practices make it desirable to preserve the identity of crude from certain producing areas, which may differ greatly in specific gravity and physical composition from crudes in neighboring areas, and require separate deliveries to the refinery. Delivery of two or more separate and distinct grades of crude through a single-line pipe-line system is accomplished by "batching"; that is, the batches of different grades, which may be 10,000 or several hundred thousand barrels in volume, are pumped through the pipe line in successive rotation, one immediately behind the other.

These batching operations, through pipe-line systems usually several hundred miles long, present many problems, one being to prevent mixture or intermingling of the crudes at the interface of the opposing columns as they travel through the pipe line; in other words, to prevent a mixture between the heads and tails of the batches. In the absence of a better method of preventing this contamination the usual practice has been to insert between batches a mechanical device known as a "pipe-line scraper" or "go-devil" which was originally designed for removing paraffin deposits from the internal surfaces of pipe lines and has been in general use for this cleaning service throughout the industry for over 20 years.

The use of ordinary pipe-line scrapers has proved unsatisfactory for

Fig. 1. Design of 8-in. batching scraper for crude segregation.

batching operations due to inefficiency and high maintenance costs. It became evident that a special separating device should be used and, as none was available on the market, one major pipe-line company solved this problem by providing a specially designed plug or scraper. This special device (Fig. 1), which will be called a "batching scraper" due to its similarity to the conventional type, subsequently proved to be very successful. Before continuing with a report on its construction it will be necessary first to discuss briefly the mechanical principles involved in the operation of scrapers so that a better comparison may be made of the mechanical features, initial and maintenance costs, and advantages in batching operations of the new batching scrapers with respect to the old-type scrapers previously used.

Operation of Scraper—The old-type scraper is propelled through the pipe line by the force of the oil stream acting against circular disks. Friction between the moving scraper and the pipe wall resists the force of the stream, consequently a hydraulic pressure drop is set up from the rear to the front of the scraper which tends to produce a flow of oil around it. This continual bypassing of fluid results in the scraper traveling at a slightly slower rate of speed than the stream, and in traveling a distance of many miles it is evident that a considerable volume of oil from the batch of crude in the rear may be permitted to flow around the scraper and mingle with the dissimilar batch of crude ahead. It follows that in designing a special scraper for batching operations every effort must be made to reduce friction, thereby reducing the pressure drop across the scraper, also to maintain an effective seal between the propelling disks and the pipe wall so that a minimum amount of oil will flow by the scraper.

This company installed flat rubber propelling disks on all of its factory-made scrapers about 5 years ago through the use of shop-made adaptor parts; and later, in cooperation with a leading rubber company, developed the cup-shaped synthetic-rubber disk shown in Fig. 2 which was subsequently patented. These alterations improved the scrapers for both cleaning and batching operations; however, entirely satisfactory results were not obtained and high maintenance costs persisted.

It may be observed that a pipe-line scraper is composed of over 100 separate parts constructed of small bronze castings and machined-steel shapes. Knives scrape the inside pipe wall to remove paraffin deposits. The guide wheels attached to the ends of guide arms rotate against the pipe wall and serve to support the scraper. In traveling distances of many miles these parts are subjected to an enormous amount of wear and our experience has been that the complete assembly of knives and wheels must be replaced after each run of 40 miles, at a cost of about $10 for parts alone. In addition to replacements, due to normal wear, these projecting parts frequently catch on the seat rings of gate valves, pipe couplings and other obstructions in the line and are broken. When such failures occur the entire scraper is likely to lodge in the line and be demolished by the force of the oil stream. A complete new size 8-inch scraper may be purchased for about $70, list price.

Since the company maintains a well equipped and efficiently organized welding shop, combined with a modern machine shop, it was decided to develop a design which would utilize the economy and facility of the arc welding process and could be constructed of scrap materials available from other fabricating work conducted in these shops. The use of steel castings was briefly considered but was discarded as impracticable due to limited application, excessive weight and the prohibitive cost of special patterns,
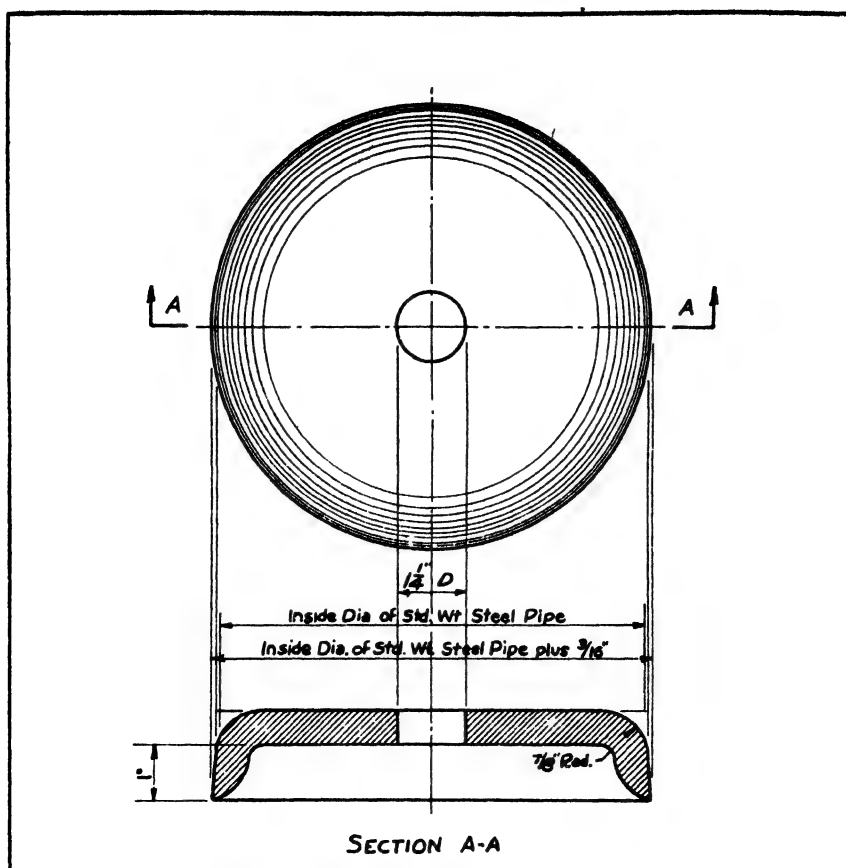
Fig. 2. Cupped rubber disk for line scraper.

also in view of the fact that it would have been necessary to obtain these castings from an outside concern at a time when such materials are urgently needed in the national war effort.

As a result, the simplified size 8-inch batching scraper, previously referred to and illustrated in Fig. 1, was designed. Guide arms and scraper knives were dispensed with since they serve no useful purpose in batching operations, produce friction, and are expensive to maintain in good repair. The use of cup-shaped synthetic-rubber disks was retained as it was thought they would effect a more positive seal against the pipe wall than any other type of disks available. The principal parts constituting the complete assembly and their purpose are as follows:

(a) Two size 8-inch cupped synthetic-rubber disks, the purpose of which has already been mentioned.

(b) Two flat-type synthetic-rubber disks which provide additional support for the flexible cupped disks. These are obtained by salvaging worn-out disks from the next larger size scraper and turning on a lathe to the dimensions given.

(c) A front body which consists primarily of a circular steel plate for

supporting the rubber disks and a conical-shaped framework for guiding the scraper through gate valves in which the steel disks might lodge.

(d) A central body of the proper length to place the rubber disks a distance apart sufficient to span the annular space between the seat rings of gate valves and side openings in the pipe lines where branch lines are connected. It should be observed here that if both disks were placed within the limits of such openings the scraper would lodge as the oil stream would be permitted to flow around it.

(e) A long bolt through the center for assembling the component parts and to permit the replacement of the rubber disks which incidentally are the only parts subject to wear.

(f) Two steel bushings, cut from 1¼-inch pipe, slightly shorter in length than the thickness of each pair of rubber disks. These bushings materially increase the resistance of the body to bending stresses by providing metal to metal contact throughout the entire length of the scraper after the bolt is tightened sufficiently to compress the rubber disks.

Three size 8-inch batching scrapers were built in the company's combination welding and machine shop during the month of April 1942. The unit construction costs are reproduced below:

Material			
2	new 8″ cup-type rubber disks at $4.80 each	$ 9.60	
2	salvaged 10″ flat rubber disks at $1.50 each	3.00	
0.5	sq. ft. ⅜″ second-hand tank steel	.25	
0.4	sq. ft. ¼″ second-hand tank steel	.10	
1.0	sq. ft. 3/16″ second-hand tank steel	.30	
1.6′	1¼″ std. BM pipe	.18	
1.6′	1″ extra heavy seamless pipe	.36	
1	1¼ by 6½″ machine bolt with nut	.33	
2	lb. Fleetweld No. 5 electrodes	.15	
	Total material	$14.27	$14.27
Labor			
Cutting—1 hr. at $1.07		$ 1.07	
Alignment and welding—2 hr. at $1.28		2.56	
Machine work—1 hr. at $1.28		1.28	
Assembly—½ hr. at $1.07		.54	
Shop overhead		2.00	
	Total labor	$7.45	7.45
	Total cost for each scraper		$21.72

As mentioned before the initial cost of an 8-inch scraper of the type previously used is approximately $70. Subtracting from this the cost of constructing the new scrapers, at $21.72 each, the unit saving is found to be
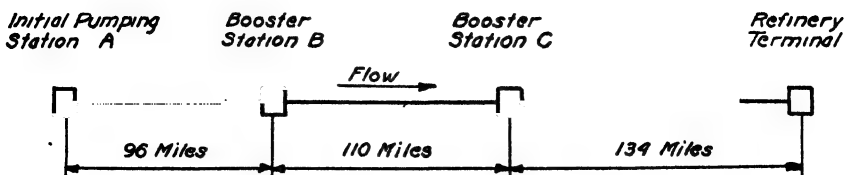
Fig. 3. Plat of line on which test was made.
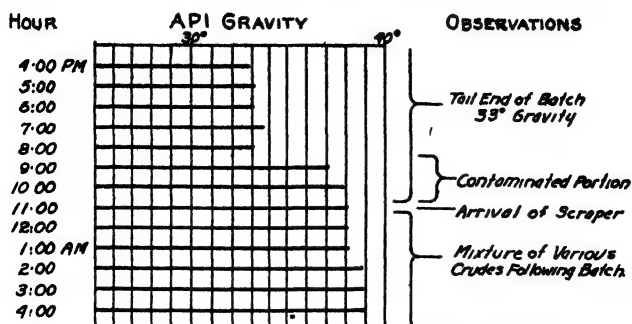
Fig. 4. Observation of oil run with old-type scraper showing mixing of batches.

$48.28. Quantity production of 12 to 15 units at a time probably would reduce the labor and overhead costs to about $5 each. Further development may increase the material costs. One improvement being considered is the use of the more expensive high tensile steels which would permit a reduction in weight by decreasing the thickness of the tubing and plates; however this must be postponed until the current shortage of special steels is abated.

Attention is called here to the fact that this is an example of the economies reflected by changing a complicated design composed of cast and machine-made parts to a much simplified design made possible by the development of the arc welding process. It is not a cost comparison of different methods of producing an identical design.

These batching scrapers were first used in a batching operation through an 8-inch single-line system briefly diagrammed in Fig. 3.

As a means of checking the degree of contamination between batches of crude the procedure has been to take A. P. I. gravity readings of samples drawn from the oil stream at Booster Station C at 30-minute intervals during the period when the batching scraper is expected to arrive at this point. Charts are reproduced below of hourly average gravity readings taken at the tail ends of two batches of the same type of crude which passed Station C on April 9, 1942, and May 2, respectively. In the first operation an old-type scraper was used with cup-shaped rubber disks installed. In the second operation the new batching scraper was used.

An inspection of these charts reveals conclusive proof of the superior efficiency of the new batching scraper. In the first case, Fig. 4, at the time
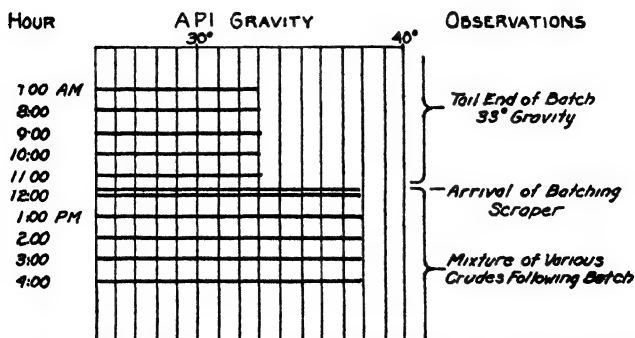
Fig. 5. Observation of oil run with batching scraper showing complete separation.

the old-type scraper had arrived at Station C it had lagged behind the interface of the opposing columns of oil which resulted in the contamination of approximately 400 barrels at the tail end of the batch. In the second case, Fig. 5, the new batching scraper arrived at Station C at approximately the same time as the interface of the columns and a clear separation between the crudes was maintained.

Three of the new scrapers were used in carrying out this batching program from Station A to the refinery terminal, approximately 340 miles apart. At the completion of the operation all three were in good condition except for normal wearing of the rubber disks which would have occurred on any type of scraper used. Although a record was not kept of the repair parts required for the old-type scrapers in the previous batching operation, it is estimated from past experience that at least eight sets of knives and guide wheels would have been worn out and replaced at a cost of $80. Other repair parts and labor probably would have increased this expense to at least $150, all of which was avoided by the use of the new batching scrapers.

The first trial of the new batching scraper also revealed its advantage for use in cleaning the internal surfaces of pipe lines, a result which was not anticipated. A considerable amount of sand and mill scale was received from the line immediately in front of the scraper at Station B, sufficient in volume to foul the pumps and necessitating the repair of the pump valves. This portion of the company's pipe-line system was constructed in 1939 and since that time conventional scrapers had been run numerous times for the purpose of cleaning the lines. At no previous time had amounts of sediment greater than a few gallons been removed. Scrapers were run only 3 months prior to the batching operations discussed. One would expect that all foreign objects, such as mill scale, left in the line at the completion of its construction would have been removed during the first year of operation. The fact that the new scrapers thoroughly cleaned the line of sediment passed over by the old-type scrapers shows their superiority for this service.

Due to the satisfactory results of this experiment, the company proposes to construct additional batching scrapers, of sizes suitable for pipe lines of various diameters, to be used in future crude batching operations. If later experiments substantiate the above evidence that the wiping action of the rubber cups thoroughly cleans the line without the use of expensive knives and wheels, their use will be extended to this essential service as a means of reducing the high maintenance costs involved in periodical, internal cleaning of the several thousand miles of pipe line operated.

A conservative estimate of the gross annual savings, accruing to this company through the use of batching scrapers, may best be based on the total number of old-type scrapers in service. A recent survey of the entire system revealed that approximately 200 scrapers varying in sizes from 3-inches to 14-inches are in service, the average size being 8-inches. At least 25 new scrapers are required each year for replacements and extensions of operations. Considering the cost of the 8-inch size as a fair average, a direct saving of $1,207 would result from filling this requirement with the new batching scrapers built in the company's shop which, as stated above, may be produced at a cost of $48.28 below the purchase price of scrapers of the old type.

It is estimated that the total annual cost of repair parts for the old-type scrapers, not including rubber disks, is in excess of $5,000. A policy of discontinuing the purchase of scrapers, if adopted, would eventually result in the exclusive use of batching scrapers, in which case the $5,000 yearly operating expense would be eliminated.

Sources of information available to the author regarding the extent and economies of batching operations conducted by this company are inadequate to evaluate in dollars the annual benefits to be derived from the use of the new batching scrapers in these operations only. However, it may be said that the purpose of batching different grades of crude is becoming more prevalent with this company as well as others engaged in the transportation of crude oil and its success is dependent upon a practical and efficient mechanical device, such as the one described above, for maintaining a clean-cut segregation between batches. A device of this kind is more urgently needed among pipe-line companies engaged in the transportation of refined products where it may be necessary to handle through a single-line system as many as seven different products, ranging from the heavier fuel oils to high-test gasolines, which are relatively more valuable than unrefined crude oil.

In conclusion, the facility with which this special tool was produced demonstrates the unlimited possibilities in the application of arc welding for producing substitutions for special tools and equipment, essential to the operation of companies not engaged in manufacturing, which may soon be unavailable from the usual sources. If such companies are to continue to operate efficiently throughout the present national emergency much ingenuity must be exercised along these channels.

Chapter XXVII—Modern Welded Blast Furnace

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Regis F. Fey

Subject Matter: The design, function, construction, cost and features of a welded 1,000-ton-per-day blast furnace. This blast furnace, complete with auxiliary equipment, was constructed in eight months' time as compared to twelve months for a similar riveted furnace. The welded furnace and equipment as compared to a similar riveted unit reduced the weight 417,000-pounds or 12.9%, drafting cost $4,257 or 41.1%, fabrication cost $48,959 or 39.9%, erection cost $45,800 or 44.5%, total cost $153,830 or 35.2%. A lower maintenance cost is anticipated by using arc welded furnaces.

Battleships, destroyers, tanks and jeeps are continuously rolling off our production lines. What burden does this place on the steel industry? Just this: 2,800-pounds of steel to build a jeep, 28-tons to build a medium tank, 2,000-tons to build a destroyer and 40,000-tons to build a battleship. Each blast furnace built by arc welding increases production by 130,000-tons—enough iron, when refined into steel, to build 93,000 jeeps, or 4,600 medium tanks, or 65 destroyers or even 3 battleships.

This increased production, so vital at present, is created by the reduced time required to build a welded blast furnace by permitting its operation to begin months earlier. The conventional riveted blast furnace requires 12 months to build. The first welded furnace we built began pouring iron eight months after work was started.

This modern welded furnace only recently has been adopted by the steel industry. During the period from 1930 to 1938 when arc welding was rapidly replacing older methods of fabricating steel in many industries, the steel industry itself was operating essentially with equipment built prior to that period. This was particularly true of the 220 blast furnaces in the United States.

Recently the rapid increase of steel consumption by defense industries has caused the need for a considerable expansion of iron and steel production equipment. The blast furnace with its appurtenant structures is an important producing unit of the steel industry. Several new blast furnaces have recently been built or are in the process of construction to meet this rapidly increasing demand for steel.

One of the first furnaces to be built under the expansion program was Furnace No. 3, being fired in December, 1941, with a rated capacity of 400,000 tons a year—slightly more than 1,000 tons a day. In the fabrication of this furnace, the advantages of arc welding were applied to all of the structures consisting essentially of steel plate work—the blast furnace shell, mantel, tuyere breast jacket, bosh bands, hearth jacket, dust catcher, whirler, hot blast stoves, gas and air piping and walkways.

When the recent rapid expansion of the steel industry became necessary,

it was thought by some, that to save time in building new furnaces, duplicates of the older furnaces should be made. This would eliminate to a certain extent, the preparation of new designs and detail drawings. But upon further consideration, the advantages of arc welding offset this savings so that practically all of the furnaces built recently have been, welded.

An example of this trend is the installation in which the steel company, acting as general contractor on this project, had requested separate bids at different times on the various steel structures. The first of these was the blast furnace shell and mantel based on a riveted design. We suggested as an alternate an arc welded design. The estimated cost of the two structures indicated a substantial savings by using the welded design, (See Fig. 1). In view of this fact, the remaining structures were then considered only on the basis of a welded design.

Design and Function—In the following description of the steel design of the various structures, their functions in the operation of the blast furnace is also outlined.

The extraction of metallic iron from its ore is performed in the furnace stack. Into the top of the stack is placed iron ore, coke and limestone in the proper proportions. Preheated air is forced in near the bottom. The intense heat of combustion melts the iron and slag impurities which then flow toward the bottom of the stack. The molten iron and slag is drawn off through notches near the bottom. The operation is continuous. The loading of the ore, coke, and limestone and the drawing off of the molten iron and slag are intermittent.

The other structures are used either to place the materials into the top of the stack, to clean the exhaust gas, to preheat the air draft or to convey the gas and air to the various processes.

The blast furnace and its accessory equipment including the gas cleaning apparatus, the piping and the hot blast stoves were designed for an internal pressure of 30-pounds per square inch. In addition to this pressure, the weight
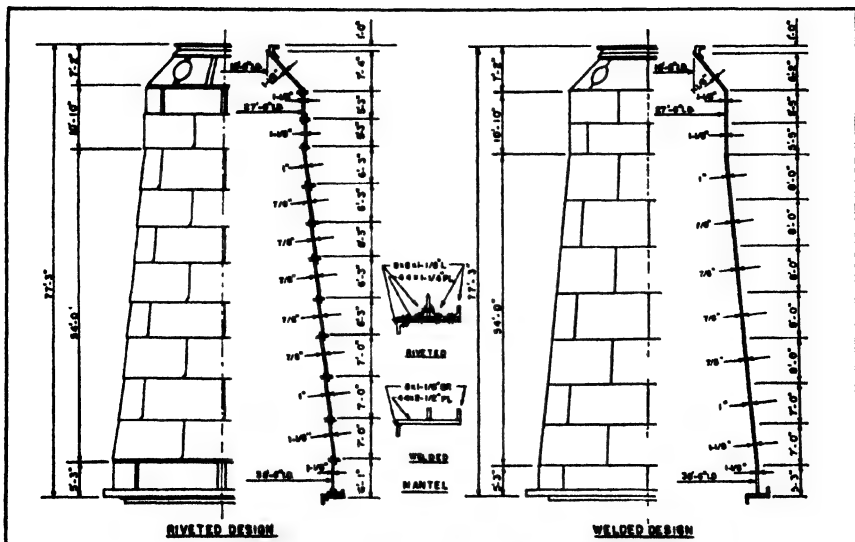
Fig. 1. Blast furnace shell.
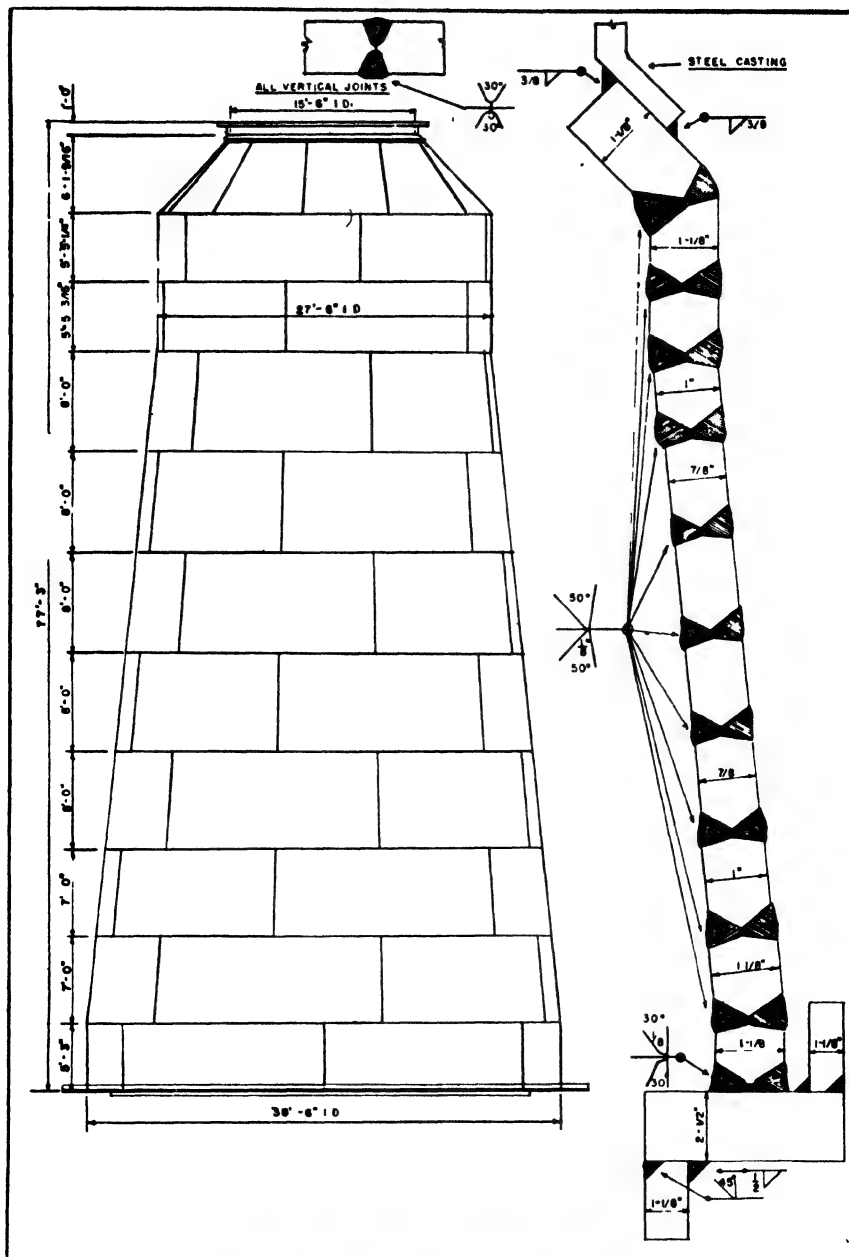
Fig. 2. Welded blast furnace shell.

of the structures, the loads of ore, coke, limestone, dust, brick lining and wind were considered.

Furnace Shell—The furnace shell, made of 7/8-inch, 1-inch and 1 1/8-inch plates, was entirely butt welded, (See Fig. 2). It has eleven courses, six plates to the course. All of the vertical joints were of the double U type, fabricated

by planing. The horizontal joints were double V. These edges were burned. The bottom of the shell was welded to the mantel with a double J joint.

The mantel, having 1⅛-inch thick flanges and a 2½-inch thick web was also butt welded. It was shop fabricated in eight sections. The flanges were designed and shop welded to the web in such a way so as to reduce to a minimum the tendency to warp or distort the sections. In the field, these sections were welded together to form a complete ring. The webs all were joined by using a deep single U joint. This permitted all down welding.

At the top of the shell, the top ring steel casting, made in four parts, was attached to the plate with welds as small as was practical—⅜-inch fillets on each side.

The butt welded joints of the shell and mantel required special consideration in detailing the plates. A shrinkage of ⅛ inch was anticipated at each joint in the shell plates. Therefore, the plates were detailed and fabricated to the size required on the basis that the edges of the plates touched, then they were erected with a ⅛-inch gap between the edges.

A special welding procedure was also necessary. The method was to outline a means of welding the joints in a sequence so as to reduce as much as possible a tendency to distort the structure due to the shrinkage of the joints. The following is the procedure as outlined by our welding engineer.

Welding Instructions and Procedure

1. Filler Rod Metal—"Fleetweld 5" for all seams.

2. Qualification of Welders—All welders must have passed previously the A. W. S. Qualification Test for the types of joints shown on the drawing or they must take the A. W. S. Qualification Test on the job before starting to weld. A record of each welder shall be kept by the foreman and papers for each new welder should be sent to the office.

3. General—Each bead of welding shall be peened only sufficiently to break up slag. Chip out all cracked and poorly fused tack welds.

4. Procedure—(a). Erect mantel sections FM1 and FM2 and tack them together with the edges of the mantel sections in contact. Do not attempt to bolt the mantel ring to the columns with the 2-inch round bolts before the mantel is entirely welded. The mantel ring has been fabricated oversize to accommodate the welding shrinkages in the joints, and it is, therefore, impossible to line up the holes in the mantel with the holes in the top of the columns until the mantel has been completely welded. The mantel, may, however, be bolted lightly to the columns so as to hold it in approximate position with bolts that are 1½-inches or less in diameter. These bolts must be removed after the joints of the mantel have been continuously welded and replaced with the 2-inch round bolts.

(b), Establish the inside of the shell with punch marks spaced at about 12-inch or 18-inch intervals on the top surface of the mantel.

(c), Erect the first ring of the shell by first tacking the vertical joints and then tacking the first ring to the mantel so as to hold the inside of the ring to the punch marks.

(d), After the first ring is rounded out and tack welded, the remainder of the shell and furnace top may be erected.

(e), Weld at least one-half of each vertical joint above and below a horizontal before that horizontal joint itself is welded.

(f), The furnace top should be welded in the following sequence: the radial joints first, the top plates to the shell second, and finally the plates to the top ring casting.
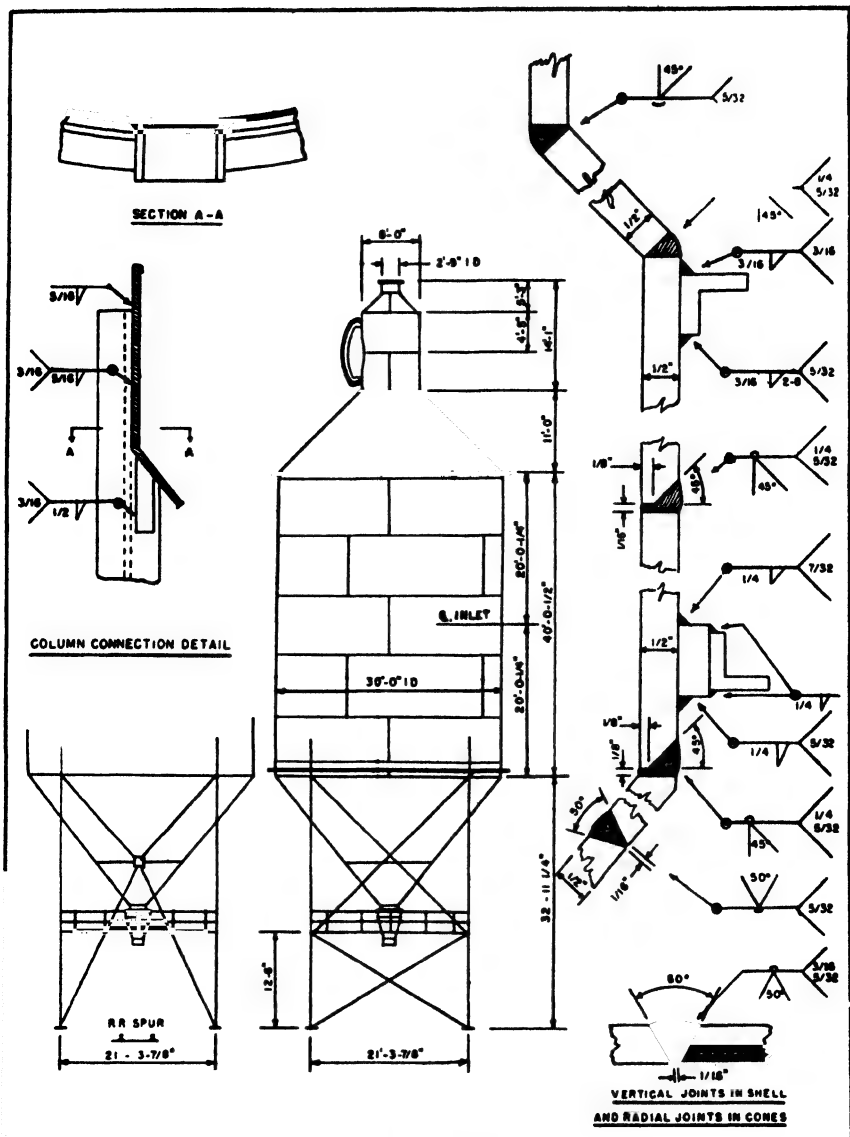
Fig. 3. Dust catcher.

(g), Erect and bolt the liner castings on the furnace top after it has been entirely welded.

A furnace shell requires exceptional care in fabrication and erection so that the complete structure is accurate in alignment and elevation. After this shell and top casting were erected and welded, a plumb-line dropped from the center of the top casting to the bottom of the furnace indicated no measurements out of alignment from the center of the furnace at the bottom. Measurements to determine the actual elevation at the top of the flange of the casting indicated a difference of only 1/16-inch from the previously figured elevation.

These results indicated a thorough understanding of welding shrinkage and distortion problems and applying this knowledge to the fabrication and welding procedure of the structures.

It may be noted that during erection and welding there is a certain amount of control, within limits, of the alignment and elevation of the structure, while for a riveted design, these factors depend entirely upon the accuracy of shop fabrication and does not allow for adjustment in the field.

Furnace Accessories—The lower part of the furnace from the mantel to the bottom of the hearth consists of a thick circular firebrick wall. The upper portion is encased by the welded tuyere breast jacket. Through this water-jacketed band pass the tuyeres. These inject the hot air blast into the furnace. In the firebrick from the bottom of the tuyere breast jacket to the bottom of the hearth are embedded steel reinforcing bands. There are eight bosh bands made of 12- x 1½-inch bars. Each band is made in four sections Splice bars are welded to the ends of the bars in the shop. The rings are bolted together in the field. They range in diameter from 32-feet 6-inches to 38-feet 6-inches. They are placed one on top of the other, increasing in diameter toward the top. The bands are separated about 6-inches by spacer castings. Below these are four hearth jacket bands made of 12- x 1¾-inch bars. The splices are similar to those on the bosh bands.

Dust Catcher—The dust catcher, (See Fig. 3), is the first in a series of gas cleaning units. The exhaust gas from the top of the furnace is conveyed through the uptake and downcomer pipes into the side of the dust catcher. About 40,000-cubic feet of gas a minute, at a considerable velocity, passes into this large container. The reduced velocity in the dust catcher permits the larger particles of coke, limestone and ore dust to settle to the bottom. The gas then passes out through an opening at the top.

Some interesting design features of this welded structure are: the smooth inside surfaces of the butt welded plates, thus reducing abrasion of the plates by particles of the dust-laden gas: the simplicity of the column connection to the shell: the connection of the top and bottom cone sections to the shell using a butt welded joint where previous riveted designs would require expensive flanging of these plates to make a lap joint: the compression ring at the belt seam, consisting of an angle and a bar: the simple welded detail transmitting the equivalent of this section around the column connection and the plain portal bracing in two panels of the tower.

Whirler—The exhaust blast furnace gas then passes through the whirler, (See Fig. 4), at an average velocity of 550-feet per minute. The inlet gas pipe enters the shell at an angle so that the incoming gas passes around the outside of the 7-foot 6-inch diameter uptake tube in a downward rotating motion and then passes up through this tube of the next cleaning apparatus. The gas whirling at a reasonably high velocity causes the dust particles to be thrown outward toward the shell by centrifugal force. These are 24 vertical vanes attached to the lower part of the shell to catch these particles, stopping their whirling motion and allowing them to fall by gravity to the bottom of the container. A cone, smaller in diameter than the whirler itself, is placed with its apex upward in the lower part of the shell. It permits the particles of dust to fall from the vanes downward around it and also prevents the rapidly moving gas from agitating an accumulation of dust particles in the bottom.

Similar welded design features to those used on the dust catcher were incorporated in this structure. In addition, special consideration was given to the abrasion of the steel plate by the dust particles. A ⅜-inch thick abra-

Fig. 4. Whirler.

sion resistant steel plate, having a carbon content of .45 per cent was welded to the outside surface of the uptake tube and to the underside of the cone roof. These plates were attached by plug welds and joints were then sealed with a filler bead of "Shield-Arc 85" Rod. All of these welded surfaces were then ground smooth. It may be noted here that it would have been much more expensive to provide a smooth continuous abrasion resistant surface by any other method than welding. The shell plates from the cone roof down to the vanes were protected from abrasion by a brick lining.

Hot Blast Stoves—After the gas is thoroughly cleaned, part is burned

in the hot blast stoves. There are three stoves of the two-pass type, each 26-feet in diameter by 102-feet 2¾-inches shell height, (See Fig. 5). Sixty car-loads of a silica checker brick are placed in each stove. The gas burns in a brick combustion chamber which is near the center of the stove extending to the top of the shell. It then travels down numerous small passages in the brickwork near the periphery of the stove and exhausts through chimney valves near the bottom. The schedule is to heat the stoves for two hours while air is passed through them for one hour. They are operated alternately, two being heated while through the third is forced air which thereby is pre-heated to about 1,100°F. before passing to the blast furnace.

The stoves are entirely butt welded, using ⅝-inch and ¾-inch plates. The numerous nozzles were also welded. This construction facilitated the laying of the brickwork adjacent to the smooth inner surfaces. It also assured a gas tight construction.

Exhaust Stack—One stack, (See Fig. 6), serves the three stoves to exhaust the burned gas which enters through the bottom. The stack is 200-feet high by 10-feet 9-inches inside diameter, having a conical bell section 45-feet 3-inches high by 20-feet in diameter at the base. The stack is self-supporting having twenty-four 2-inch diameter anchor bolts not upset. The stack was fabricated of 5/16-inch to ½-inch thick plates, with the seams entirely butt welded.

An interesting erection feature was that the stack was so situated that a large guyed derrick placed on top of the lower 100-foot section was used to erect the steel for all the other structures except No. 3 stove where a basket pole was used. The steel plates and welded joints for this lower section of the stack were designed to withstand the loads during erection.

Piping—The miscellaneous gas and air piping is an important item of a blast furnace. The piping for this furnace ranges from 3-feet to 9-feet in diameter, fabricated from ⅜-inch and ½-inch plate butt welded. The hot blast main and the bustle pipe have a 4-inch brick lining. The offtakes, up-takes and downcomer have 0.7 per cent carbon wearing plates, welded to the inside of the pipe at the various bends.

It was originally intended to shop-weld the pipe in sections of 20- to 24-feet in length. However, during fabrication and erection the shop, due to the schedules of other jobs, was not able to supply the field crew with steel fast enough to keep them working efficiently. To relieve this situation, the shop only prepared the edges and rolled the plates. They were then shipped to the location where the field crew welded the plates into sections. The costs showed no noticeable loss of efficiency. This indicates the adaptability of welded pipe designs to production scheduling.

Walkways and Platforms—On the various structures and along the piping there are several walkways and platforms. They are used to provide access for the workmen to the various valves and other mechanism on the structures and to permit adequate working space at these places. They were made by the usual construction methods, the members being welded or bolted together. As many of the walkways were placed along the top of the piping and as the exact location and alignment of the piping in several instances were established during erection, these walkways were then of necessity "made to fit" in the field. This assured an accurate fit, a condition that scarcely could be anticipated if they were completely shop fabricated.

Proportionate Cost Savings in Percentage—A proportionate savings in the cost is indicated in the following by using a welded rather than a riveted
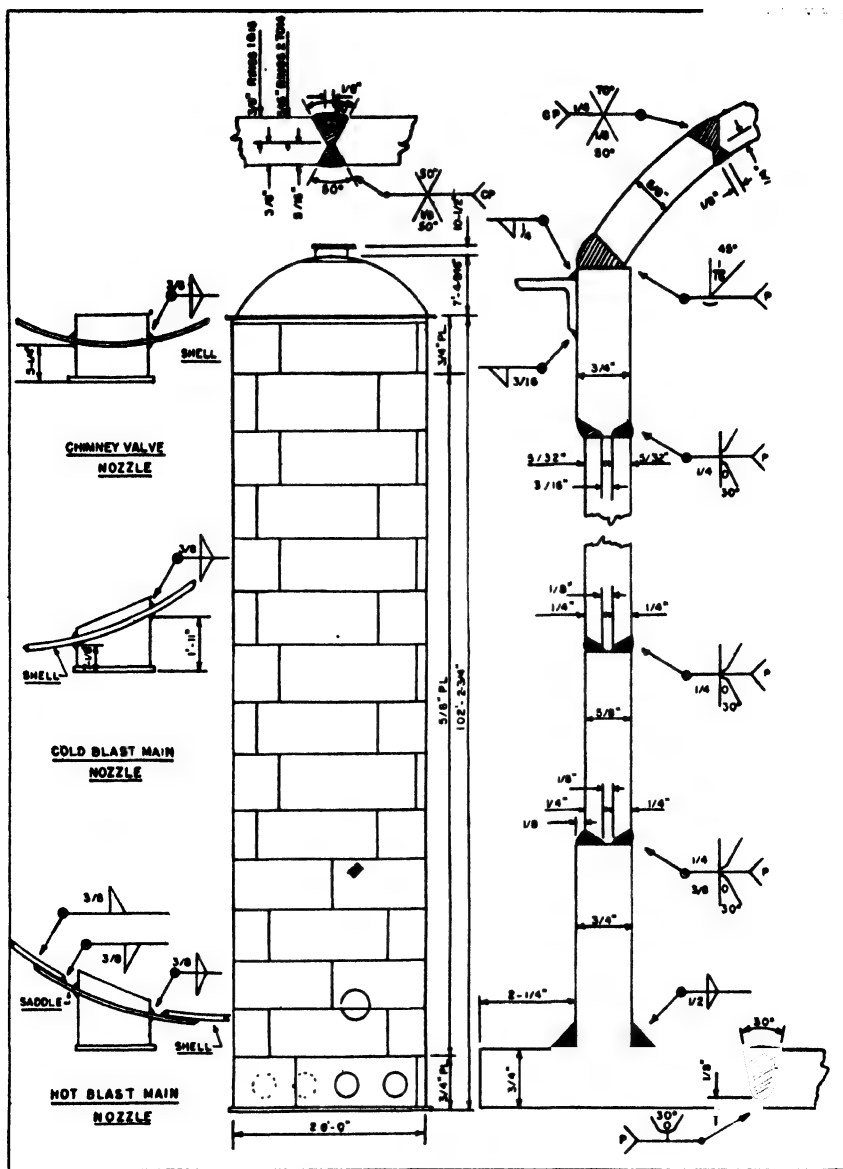
Fig. 5. Hot blast stove.

design. The savings is presented in dollars and also shown as a percentage of the cost of the riveted design.

Every item or operation which is included in the total cost of the job is considered. These include: cost of material, preparation of detail drawings, shop fabrication, freight charges, erection cost, taxes, insurance, general overhead and profit. These items are then summarized to obtain the total savings. This cost analysis reveals the proportionate savings of each item or operation.

Weight—The furnace shell, whether riveted or welded, is usually made of the same thickness of plate. This ranges from ⅞-inch to 1¼-inches de-
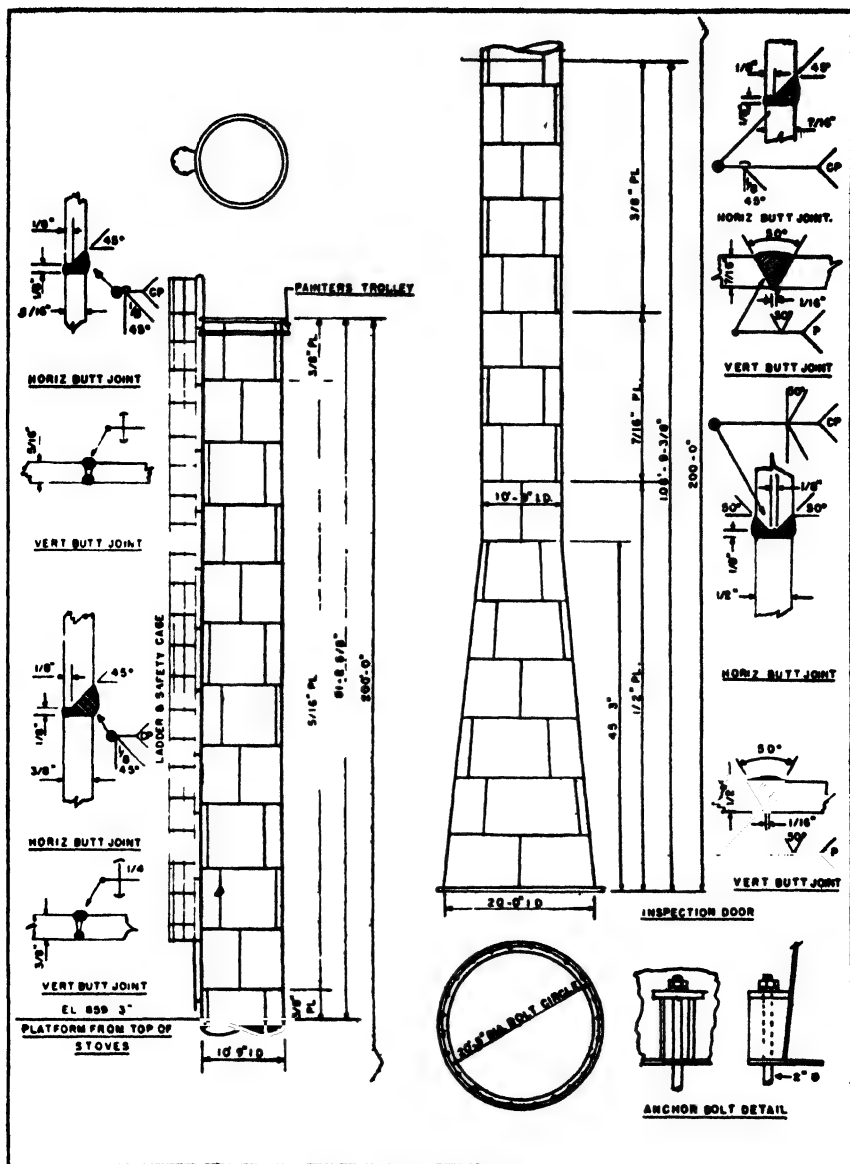
Fig. 6. Stack for stoves.

pending upon the location of the plate in the shell. The advantage of butt welding the plates arises from the consideration that the heavy butt straps or plate laps required for the riveted joints are eliminated.

The other structures, including the furnace accessories, the dust catcher, whirler, hot blast stoves, stack and piping and walkways also indicate a weight savings. These are usually made of a nominal plate thickness. Therefore, the reduction in weight by using a welded design is also reflected in the elimination of lap or butt riveted joints and in the simplification of the structural details.

The weights of the welded structures as compared with the estimated weights of these structures on a riveted basis are indicated in the following table:

Weight of Steel Structures

	Weight of Riveted Structure Lbs.	Weight of Welded Structure Lbs.	Weight Savings Lbs.	Per Cent. Savings
Furnace shell and mantel	510,000	412,000	98,000	19.2
Furnace accessories	163,000	132,000	31,000	19.0
Dust catcher	205,000	184,000	21,000	10.2
Whirler	77,000	69,000	8,000	10.4
Hot blast stoves	903,000	832,000	71,000	7.9
Exhaust stack	153,000	138,000	15,000	9.8
Piping and walkways	1,215,000	1,042,000	173,000	14.2
Total	3,226,000	2,809,000	417,000	12.9%

On the basis of the published mill base price of $2.10 per hundredweight for steel plates and shapes plus an average allowance of 15-cents per hundredweight for unloading the steel at the fabricating plant, the cost of welding wire or rivets, and mill extras on the steel, etc., the savings in metal costs amounts to:

$$(\$2.10 + .15) \times 4170 \text{ cwt.} = \$9,382.50$$

This weight savings not only causes a reduction in the material cost but is also reflected in a lesser handling cost during fabrication and erection and a smaller freight charge in transporting the material from the fabricating plant to the erection site.

Drafting—The preparation and checking of the detail drawings for a blast furnace are considerably simplified by using an arc welded design. Fig. 7 shows the details required by the fabricating shop to make a furnace shell plate and mantel and illustrates the comparative simplicity of the drawings of the welded design. There is a similar condition for the other items on this job.

For such an installation, a considerable portion of the piping comprises bends and turns. These are made in segments having arcs from 6° to 10°. There is also a very large variety of tee and wye intersections. The development of the plates is very involved. Lap or butt riveted joints would cause many additional problems for the detailer. Butt welded joints simplify the drafting to the extent that the time required is reduced almost by one-half.

In addition, a riveted structure requires a rivet location layout indicating the size, length and number of rivets furnished and the joint of the structure where they are to be used. For a welded structure, the size of weld wire for each bead is indicated on a large scale section shown on the erection or assembly drawing. Following is a table showing the drafting costs on this job as compared to a riveted job built in 1937. The costs are given for the time required to make and check the detail shop drawings.

Drafting Costs

	Riveted Design	Welded Design	Savings	Per Cent. Savings
Blast furnace shell and mantel	$ 403	$ 265	$ 138	34.2
Furnace accessories	202	128	74	36.6
Dust catcher	654	402	252	38.5
Whirler	353	252	101	28.6
Hot blast stoves	260	196	64	24.6
Stack	215	127	88	40.9
Piping and walkways	8,270	4,730	3,540	42.8
Total	$10,357	$6,100	$4,257	35.7%

Shop Fabrication—One of the larger items of cost of the structures is the shop fabrication. Several comparisons of shop costs make the welded design more economical.

For the welded design there is a savings in unloading the steel to the stock yard and a similar reduced cost in handling and moving the steel through the sequence of shop operations because of the lesser weight.

The first shop operation is laying out the steel. This involves marking on the steel the dimensions that are shown on the detail drawings. Therefore, the time to prepare the drawings is an indication of the time to layout the steel. A comparison of the costs of this operation is similar to that of the drafting costs.

The following operations vary somewhat for the two types of design, riveted or welded. As the various structures comprise primarily steel plates their fabrication will be discussed. In the riveted design, the plates are sheared or square burned to the required size. If two plates are alike one may be used as a template for the other. Holes are punched in thin plate and holes in thick plates are sub-punched and reamed or drilled. The plate is then formed by rolling or pressing as the thickness and final shape require.

After the parts of the furnace shell are fabricated, they are assembled and while in their proper position, the sub-punched holes are reamed to size. Thus for a riveted design, the furnace must be completely erected and then dismantled to assure a proper fit in the field. For the other structures where the fabrication is considered complicated, a similar assembly procedure is necessary as in the case of a riveted design. Small items such as pipe bends are assembled and then shop riveted in sections.

Many of the plates in these structures would be bent or flanged to form a lap riveted joint. At a transition section, (Fig. 1, Riveted Design), the plate is either hot or cold worked depending upon the thickness of the plate, radius of bend and angle of flanging.

In the welded design, after the plate is laid out, the edges are prepared by either burning or planing. The plate is then formed by rolling or pressing as the thickness and shape require. Plates joined by butt welds do not require flanging at transition sections, (See Fig. 1, Welded Design). Plates fabricated for field welded construction generally do not require a shop assembly to assure an accurate fit.

A reduction in the number of pieces for an item by using a welded con-

struction is another savings indication, due to necessary connection welds. This is particularly obvious of the blast furnace mantel. A bill of material for each mantel is listed below:

Bill of Material

Riveted Design

No. Pcs.	Description	Mark	No. Pcs.	Shape	Finished Size, In.	Lengths	
						Ft.	In.
8	Mantel Sections 1 — each marked M-1, M-2, M-3, M-4, M-5, M-6, M-7, M-8	f	4	Plate	68⅞ x 1¼	14	0
		g	4	Plate	68⅞ x 1¼	14	0
		k	4	Plate	68⅞ x 1¼	14	0
		d	4	Plate	68⅞ x 1¼	14	0
		a	8	Bent L	8 x 8 x 1⅛ L	15	1⅜
		b	8	Bent L	8 x 8 x 1⅛ L	13	3¼
		c	8	Bent L	8 x 8 x 1⅛ L	13	2 7/16
		m	2	Bent L	8 x 8 x 1 L	10	8
		n	2	Bent L	8 x 8 x 1 L	10	8
		p	2	Bent L	8 x 8 x 1 L	10	8
		s	2	Bent L	8 x 8 x 1 L	10	8
		t	8	Plate	8 x 1	1	1
		....	389	Rivets	1⅛ θ	0	3½
		....	16	Bolts	1¾ θ	0	11
		....	16	Bolts	1¾ θ	1	0

WELDED DESIGN

No. Pcs.	Description	Mark	No. Pcs.	Shape	Finished Size, In.	Ft.	In.
8	Furnace Mantel Mark FM	3pa	8	Plate	48 x 2½	8	2 1/16
		3ha	8	Plate	8 x 1⅛	13	7 3/16
		3hb	8	Plate	8 x 1⅛	16	4⅞
		3pb	8	Plate	48 x 2½	8	2 1/16
		....	64	Bolts	1¾ θ	1	6
		....	110 lbs.	W. Wire	¼ θ F.W.	....	....
		....	240 lbs.	W. Wire	3/16 θ F.W.	....	....

The overhead of a weldery is somewhat lower than that of a similar shop having facilities for riveted construction. The machinery is smaller and less expensive. There are fewer tools required. Fewer operations involve lesser machinery and supervisory workmen.

Following is a table of the fabrication costs of the various structures. They reflect the various aforementioned advantages of a welded design.

Fabrication Costs

	Riveted Structure	Welded Structure	Savings	Per Cent. Savings
Furnace shell and mantel	$ 9,582	$ 5,819	$ 3,763	39.3
Shop assemble and ream holes	1,880	....	1,880	100.0
Furnace accessories	5,275	3,067	2,208	41.9
Dust catcher	6,512	3,705	2,807	43.1
Whirler	4,367	2,543	1,824	41.8
Three hot blast stoves	11,784	7,685	4,099	34.8
Stack	2,808	1,936	872	31.1
Piping and walkways	80,346	48,840	31,506	39.2
Total	$122,554	$73,595	$48,959	46.4%

Erection—The procedure was to first completely erect each structure, then to weld the joints, carefully following the welding sequence as previously outlined.

The welded design showed several advantages during erection. As previously indicated with respect to the piping, the erection crew was kept working by welding the pipe in the field. Also an uncanny accuracy was obtained in the alignment and top elevation of the furnace shell.

The erector of welded structures has the same two important tools in the field that are generally used in the fabricating shop—the burning torch and the welding machine. Of occasion he may use these to make adjustments to the shop fabricated steel. On this job, all of the openings in the structures for the pipes were burned at their proper locations, these being determined only after the structures were completely erected and welded. This procedure assured an accurate alignment. There were some instancs where the piping did not fit and adjustments were made by burning and welding. Some of the platforms and stairways on this piping were then of necessity detailed and fabricated approximately to size then "made to fit" in the field.

These advantages combined with a comparison of making a butt welded joint to riveting a joint are indicated in the following table.

Erection Costs

	Riveted Structure	Welded Structure	Savings	Per Cent. Savings
Furnace shell and mantel	$14,200	$ 7,040	$ 7,160	50.4
Furnace accessories*	....	....	....	....
Dust catcher	6,970	4,150	2,820	40.4
Whirler	2,800	1,530	1,270	45.4
Three hot blast stoves	30,400	16,700	13,700	45.1
Stack	7,950	4,950	3,000	37.7
Piping and walkways	40,550	22,700	17,850	44.0
Total	$102,870	$57,070	$45,800	43.8%

*The furnace accessories were erected in conjunction with the brickwork by the brick contractor.

Other items of cost to be considered are freight, taxes and insurance. The freight is primarily a function of the weight, the welded structures being lighter will cost less. To a lesser degree it is a function of the type of fabrication. Certain riveted pipe sections must be shop assembled and riveted. These large sections at times require an L. C. L. rate or a C. L. minimum charge, while if they are welded they may be shipped knocked down.

The cost of social security tax varies as the shop and field labor costs. As these costs are reduced by using a welded design the tax is reduced in proportion.

To protect the workmen and the company, insurance is carried during the erection of the structure. This insurance is for workmen's compensation, public liability and property damage. Its cost is set up as a percentage of the field labor cost. It is also reduced by using a welded design.

Proportionate prices and savings for the entire unit, (See Fig. 8), is summarized in the following table. These prices include the cost of materials, drafting, shop fabrication, freight, erection, social security tax, insurance, general overhead and profit. The prices of various accessories such as manholes and nozzles and cleanout doors are also included.

Total Costs

	Riveted Structure	Welded Structure	Savings	Per Cent. Savings
Furnace shell and mantel	$65,750	$39,250	$26,500	40.3
Furnace accessories	10,220	6,870	3,350	32.8
Dust catcher	27,450	18,100	9,350	34.1
Whirler	14,420	9,250	5,170	35.8
Three hot blast stoves	98,210	67,880	30,330	31.0
Stack	17,410	12,150	5,260	30.2
Piping and walkways	204,100	130,230	73,870	36.2
Total	$437,560	$283,730	$153,830	35.2%

The following table of the summarized costs of the materials and operations required to build an arc welded design as compared with the costs of the riveted design indicates that the total savings is distributed among all of the items which constitute the total cost of the job.

Summarized Costs

	Riveted Structures	Welded Structures	Savings	Percent. of Total Savings
Material	$72,550	$63,200	$ 9,350	6.1%
Drafting	10,360	6,100	4,260	2.8%
Shop fabrication	122,550	73,590	48,960	31.8%
Erection	102,870	57,070	45,800	29.8%
Accessories	21,340	12,180	9,160	6.0%
Freight	3,540	2,930	610	0.4%
Taxes, insurance, general overhead, profit	104,350	68,660	35,690	23.1%
Total	$437,560	$283,730	$153,830	100.0%

As this is a job fabricating shop where one or several blast furnaces may be built within a given year and as a blast furnace is such a large job occupying the time of various departments for a considerable part of a year it was thought better to consider a total "job" gross cost savings accrued from the use of arc welding by the company, rather than a total "annual" gross cost savings. This suggested comparison, as shown in the preceding tables, is therefore, a representative savings of the initial cost.

During these times of major adjustments, when statistical information is limited, the estimated total annual gross cost savings accrued from the use of arc welding by industry in general is restricted in this discussion to the steel industry in the United States.

In 1941 there were 55,918,000 tons of iron produced in the United States. This was obtained with the operation of an average of 220 blast furnaces at 98 per cent capacity throughout the year. The office of production management and more recently the war production board has formulated a plan to assist the steel companies to increase their production 10,000,000-tons a year. This would involve the construction of 28 1,000-tons-per-day furnaces. The program is being carried to completion as soon as possible. It is felt that at least 15 new furnaces will be built this year. Many of these, are already under construction. It is expected that, although some of these new furnaces are very large, having a capacity of 1,300-tons a day, the average will be about 1,000-tons per day.
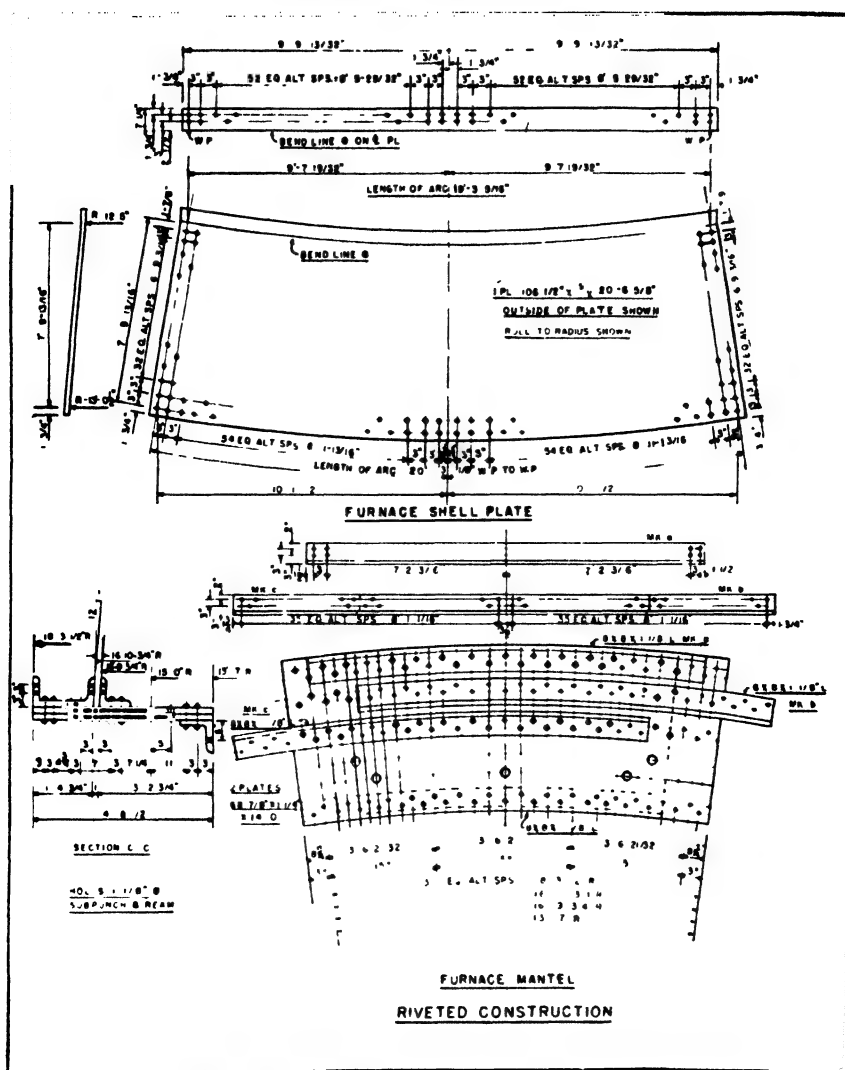
Fig. 7a. Shop detail drawing, riveted construction, furnace mantel.

Initial Cost Savings—On this consideration, the steel industry, and the United States Government, who is financing most of these projects, will save in the initial cost this year by building arc welded blast furnaces:

$$15 \times 154{,}000 = \$2{,}310{,}000$$

Next year the savings in the initial cost is expected to be greater, as the experience being now gained in building arc welded furnaces will be reflected in a lower cost of subsequent welded furnaces.

Operational Cost Savings—A lower maintenance cost is anticipated by using arc welded furnaces. The furnace, the gas cleaning structures, the air preheating structures, and the large piping operate under an average pressure of 30-pounds per square inch. Butt welded joints are a more positive form of gas tight construction than joints that must be riveted and then caulked.
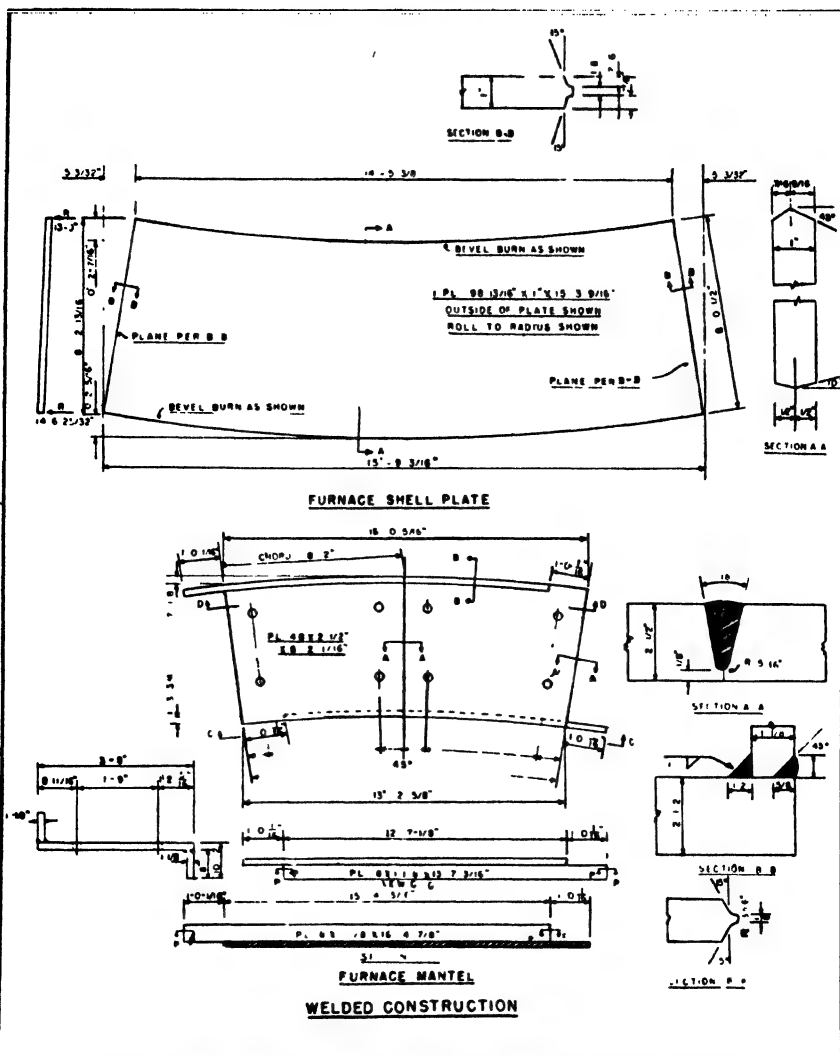
Fig. 7b. Shop detail drawing, riveted construction, furnace mantel.

This is particularly important in these structures which are subjected to a wide range of temperatures causing considerable expansion and contraction during operation. As a blast furnace usually operates continuously for several years until it must be shut down to be relined with brick, the appurtenant structures, being arc welded, will offer additional assurance of their uninterrupted service.

At times a "hot spot" develops on the furnace shell. Water is sprayed on this spot to prevent it from breaking out. This frequently causes the plate to buckle, necessitating a repair. It is much easier to patch or replace a plate in a welded shell by welding.

Newer methods and improvements of blast furnace operations require its appurtenant equipment to be removed, replaced, or revised many times during

the life of the furnace. Welded structures are more adaptable to these adjustments. A new pipe connection may be easily placed in any part of a welded structure. It is an easy matter to add on or take out a valve or a manhole in a pipe line. When an entire plant layout is revised, the appurtenant equipment and piping may be salvaged to be relocated, welded together and used again.
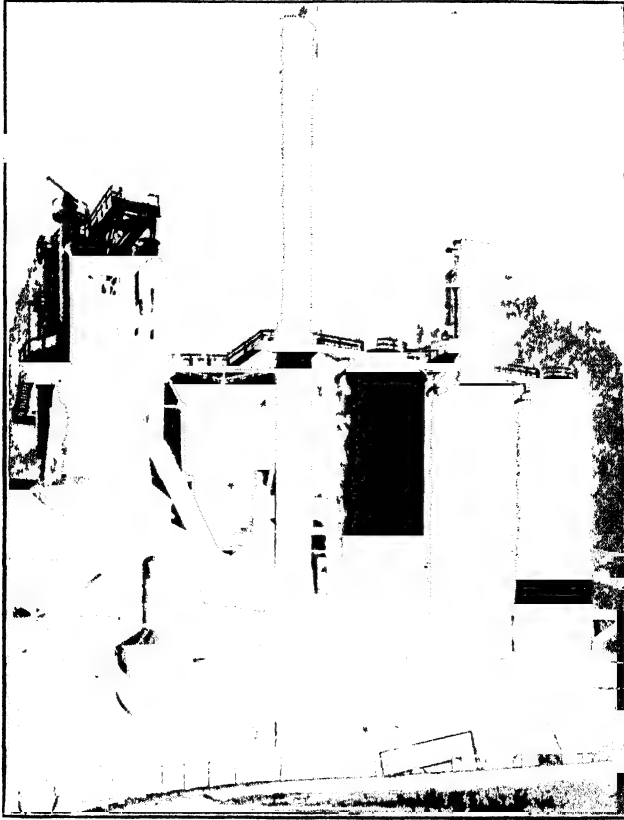
Fig. 8. The completed structure.

Frequently the hot blast main and bustle pipe must be relined. Time and labor are saved in relining the smooth inside surfaces of the welded pipe as compared to fitting the lining brick over the rivet heads and lap joints of a riveted pipe.

These operational savings will accrue throughout the entire life of the furnace—about 35 years—They are conservatively estimated by blast furnace operators as amounting to 5 per cent of the initial cost of the completed structures The cost on a complete 1,000-ton-per-day blast furnace is $3,000,000. The anticipated savings is then $150,000 per furnace.

The total annual gross cost savings to the steel industry in the United States by using blast furnaces of welded construction is the summation of the initial savings and the operational savings. When the recent expansion is completed there will be about 250 blast furnaces operating in the United

States. Conservatively, assuming no further expansion in the near future, but merely a savings derived from replacing old furnaces, the savings is:

250/35 = 7 furnaces replaced per year
$150,000/35 = $4,300 operational savings per furnace per year
Initial Cost Savings = 7 × $154,000 = $1,078,000
Operational Cost Savings = 250 × $ 4,300 = $1,075,000

Total Cost Savings per year to the steel industries in the United States....................$2,153,000

But of greater importance in these turbulent times is the consideration of public safety—of the social advantages that must be obtained and retained. A cost savings may imply greater profits. But now it takes on a more significant meaning. A cost savings, by using arc welding, is an index of the material, the man hours and the production time that it has made available to be used in making other necessary structures and war equipment.

Arc welding is assisting the expansion of our steel production at its very nucleus—the blast furnace. It is making available more iron, to be refined into steel which will then be used to make more vital war equipment.

Recently, a leading steel producer received a message radioed from Melbourne, Australia by General Douglas MacArthur complimenting them for their record breaking production. It read:—

"HEARTY CONGRATULATIONS ON THE MAGNIFICENT RECORD YOU ARE MAKING ON BEHALF OF OUR BELOVED COUNTRY."

A short time beforehand arc welding made available to the company a new blast furnace, built months ahead of schedule. This furnace increased the plant's iron production by more than one third. Therefore, fundamentally, this display of appreciation was to arc welding.

Chapter XXVIII—Carbon Arc Welding in Production of Clad Steels

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Subject Matter: The function of carbon arc welding in producing clad steels. The method of producing clad steels as described consists of two pairs of the cladding plates, with separating medium between them, "sandwiched" between thicker mild-steel slabs. The gaps at the edges, instead of being filled with weld material, are arc welded using a spacer bar of material similar to the backing plates. This new method gave a superior weld in much less time with an average 10% saving in slab weight. This resulted in a saving of $16,537.50 in 14 months. The paper also describes special arrangements, welding units, magnetic boot and cooling system used in this process.

L. W. Townsend

In the majority of cases, relatively expensive metals such as copper, nickel, and stainless steel, are utilized because they serve certain useful functions such as corrosion and oxidation resistance. In the majority of cases, these superior inherent properties are required on the surface only; for example, a brine tank need have corrosion resistance only on the inside. Since these materials are relatively expensive, economy could be and has been effected by developing combinations of these expensive materials with ordinary steel plate; such composite plates or sheets are customarily referred to as "clad metals". The production of stainless-clad steel, for example, in 1941 was approximately 8,000,000-pounds, as compared to a production of solid stainless steel in sheet and plate form of 800,000,000-pounds. It is, therefore, obvious that the present production of stainless clad is but a very small proportion of the over-all picture. It is equally true that a far greater proportion of solid material could be produced and used in clad form; its production has been increased this year and it will no doubt increase to a far greater extent in the future. Whereas many products are being produced in great quantities at the present time because of the war, stainless clad should continue to grow indefinitely.

One of the several effective methods of producing clad metals is the "assembly method". If reference is made to Figs. 1-A and 1-B, it will be noted that a pair of plates, with a separating medium between them, is "sandwiched" between two relatively thicker mild-steel slabs. These mild steel slabs are also relatively longer and wider. Into the resulting gaps are placed spacer bars of the same analysis as the backing steel. The assembly is then peripherally welded to hold the components together and to occlude furnace gases during heating. Such an assembly, after welding, is heated to approximately 2250° Fahrenheit and then rolled on the conventional plate mill; after
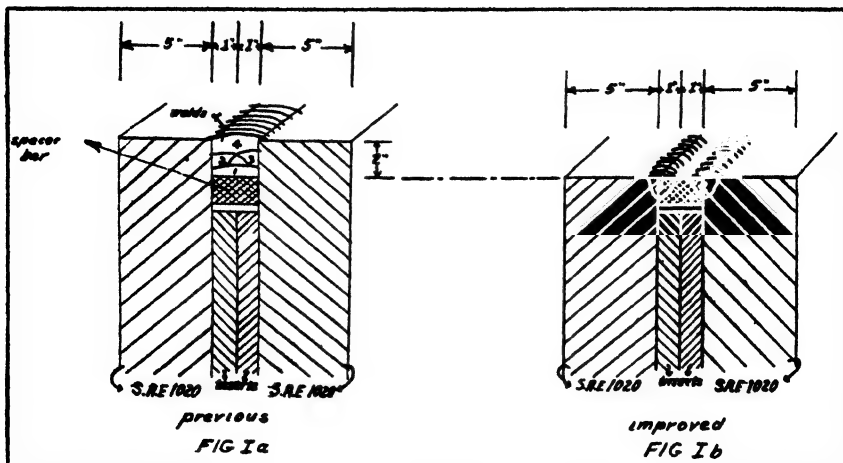
Fig. 1a and 1b. Preparation for welding.

rolling and necessary sub-processing, the rolled plate is sheared into the separating plane, resulting in two clad plates.

Since the assembly must be reduced as much as twenty times through very powerful rolls, it is obvious that the welds must have great strength at elevated temperatures. The method of welding originally employed required deep welding grooves; these grooves were effected by making the backing plates considerably longer and wider than the inserts and spacer bars combined. These grooves had to be at least ¾-inch deep and as deep as 2½-inches on very heavy assemblies Then the welding groove was completely filled with weld metal; obviously very substantial amounts of weld metal had to be deposited In addition, the weld metal was simply laid into the groove and did not necessarily effect a deep penetration into the backing steel; in other words, the final weld is not necessarily ideal

In the Fall of 1940, a welding equipment manufacturer held a series of lectures on welding, during which reference was made to carbon arc welding equipment. At that time, it occurred to the writer that this system might be applied to our assemblies to very good advantage. Instead of depositing an appreciable amount of weld metal, we would simply melt the components and replace the oxidation loss with a relatively small amount of filler wire. Further, we could reduce the size of the backing plates to the extent that the edges of the backing plates would be parallel to the outside face of the spacer bar rather than extending considerably beyond It also seemed logical that we might effect a superior weld, since we would get considerably more penetration with the carbon arc weld than we did previously. The former method employed was not fast, especially on heavy slabs, whereas the carbon arc welding was not only faster, but it was possible that one pass would serve where 2, 3 or 4 passes had been utilized previously. Inasmuch as we were cutting down the amount of metal deposited and the time required, it followed automatically that the welding cost should be less and apparently appreciably so.

Reference to Table I substantiates in detail our expectations as to the savings in weight and, therefore, the increase in yield—which is the fundamental method of cost improvement in a steel mill.

In Table II, there is presented a breakdown of the costs in connection with the carbon arc welding system now employed. The figures given as to savings for a converter of such slabs are accurate. The figures given as a comparison of the previous welding costs can only be estimated, since those figures are not available to us; however, every effort has been made to substantiate these figures and we have reason to believe that they are substantially accurate.

Table I—Savings in Weight, Typical Examples

Former Size	Present Size	Former Weight	Present Weight	Saved
2½" × 31" × 50"	2½" × 30" × 50"	1,115#	1,060#	4.95%
3" × 28½" × 52½"	3" × 27" × 51"	1,270#	1,170#	7.90%
5" × 34¾" × 58"	5" × 32¼" × 55¾"	2,870#	2,550#	11.12%
7½" × 37" × 58½"	7½" × 34" × 55½"	4,620#	4,010#	13.20%
10" × 35¾" × 44¾"	10" × 32¾" × 41⅞"	4,565#	3,840#	15.90%
15" × 36" × 48"	15" × 32" × 44"	7,350#	5,975#	18.70%
20" × 47" × 62"	20" × 42" × 57"	16,500#	13,550#	17.85%*
25" × 53" × 66"	25" × 48" × 61"	24,800#	20,750#	16.30%*

*The reason these decrease in percentage is that over 15" total thickness, by the previous method, the depth of the groove remained constant so the sidescrap is less in proportion to total weight.

Our average slab weight since adoption of the present method is 2,625-pounds. Therefore, the over-all savings have been almost exactly 10 per cent.

1200 assemblies have been welded using the carbon arc welder. Thus, at an average of 2,625-pounds per slab, the total weight welded to date is 3,150,000-pounds. At the average saving of 10 per cent, we arrive at a total savings of 315,000-pounds in 14 months.
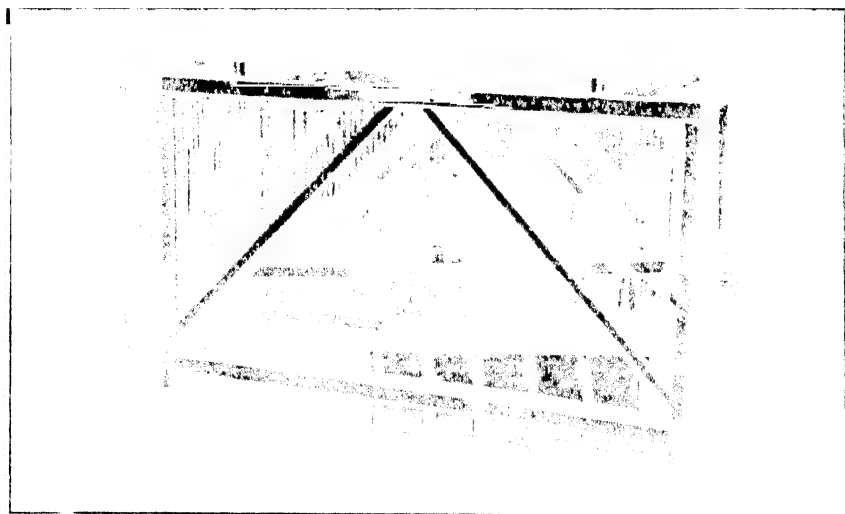
Fig. 2. Four-post gantry developed for welding.

Table II—Analyses of Costs

For the Converter—The company selling the stainless clad pays the company which does the assembling, welding, heating, rolling, etc., an average of $.0525 per pound of the assembly weight. Thus, the seller has saved 315,000-pounds by $.0525 or $16,537.50 in the 14-month period.

The following cost figures in detail cover 1100 assemblies, 2,885,798-pounds. The average assembly was 33-inches by 47-inches by 6-inches, and the average weight was 2625-pounds.

Cost to Weld	Total
Welding Carbons	491.12
Filler Metal	796.34
Steelflux	1,807.92
Overhead	700.12
Power	559.78
Supplies	512.91
Maintenance	901.39
Engineering Expense—Misc.	229.41
Labor—Operating Welder	8,035.03
Social Security Taxes—Labor	190.80
Workmen's Compensation Insurance	65.32
Depreciation on Equipment	1,737.99
	16,028.13
Administrative and General Expenses	
Interest	128.28
Public Liability Insurance	57.50
Taxes	855.27
Salaries	2,350.00
Organization Expense	272.20
Office Expense	88.36
	3,751.61
Total Expense	19,779.74

Cost per pound = $19,779.74 ÷ 2,885,798 pounds = $.00685.
Total number lineal feet welded—29,326.
Ultimate Cost Per Foot = $19,779.74 ÷ 29,326 pounds = $0.6744.
Labor Cost Per Foot = $6,035.03 ÷ 29,326 = $.2057.
Power Cost Per Foot = $559.78 ÷ 29,326 = $.0190.

Comparison of Methods*
On a Per Foot Basis

Total Thickness	Number Welds per Side Former Method	Number Welds per Side Carbon-Arc	Previous Cost per Foot	Present Cost per Foot
3"	1	1	$0.7500	$0.6744
5"	2	2	1.5000	1.2126
7½"-10"	3	2	2.2500	1.2126
Over 10"	4	2	3.0000	1.2126

*We did not have the cost figures on the previous method, but from very close contact with that machine and costs from similar machines, we feel our estimates are conservative.
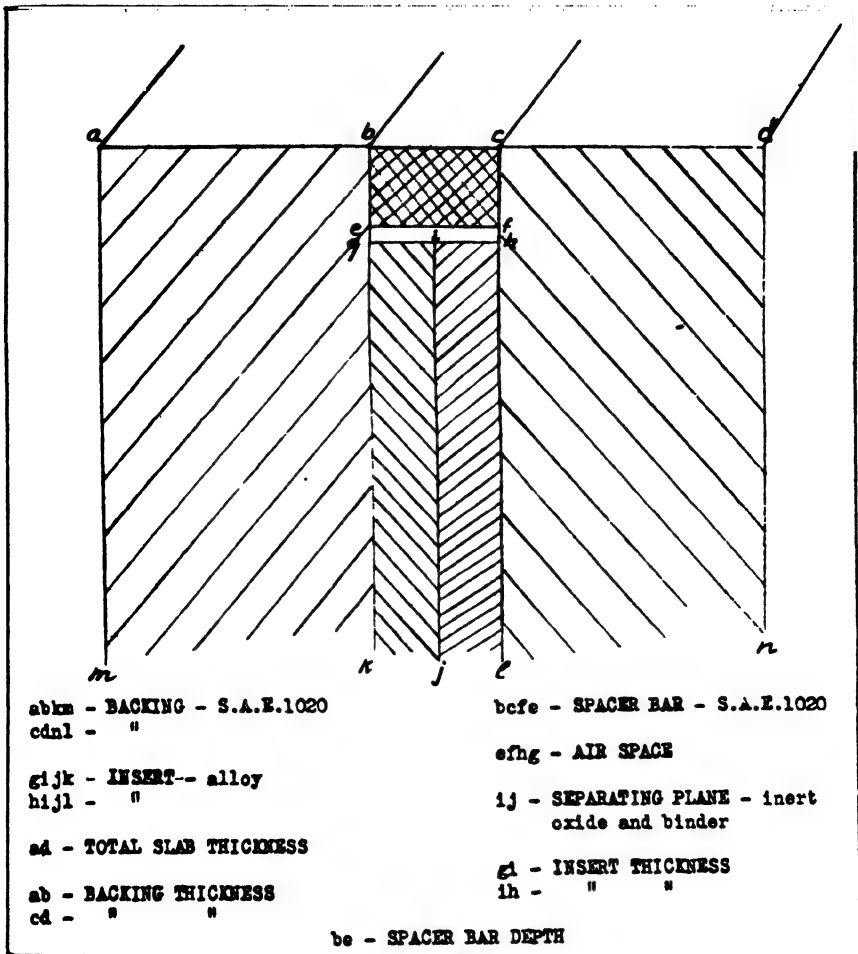
Fig. 3. Nomenclature.

Several test assemblies were made up and carbon arc welded in a shop having approximately suitable equipment; each of the trial assemblies was processed in the usual manner and found satisfactory. Therefore, orders were placed for a twin "Electronic Tornado" carbon arc welder and two 400-ampere generators. The welder was specified to be of the tractor type so that it might operate on beams or on flat plates. Also, the machine was designed and supplied to operate with ½-inch diameter carbons

The problem then arose as to the best means of handling the assemblies; in our case, the original cost was of particular importance. Would it be cheaper to make the welder more or less stationary, or would it be more satisfactory to arrange for considerable mobility of the machine? Since the welder weighed some 400-pounds and the slabs ran up as high as 25,000-pounds, it was decided that it would be more economical to make the welder movable within a considerable range, rather than moving extremely heavy slabs. If the reader will refer to the photograph, Fig. 2, and sketch, Fig. 3,

he will observe that we developed a four-post gantry which moves on rails; it has a travel of sixty feet up and down the shop. The cross beams are arranged so that they may be adjusted transversely and perpendicularly within the frame. The transverse and perpendicular motions are operated through an electric motor; the gantry is moved with a railroad jack which is satisfactory, since it is not moved more than two or three times per turn, and it moves reasonably easily—two men can push it. The two beams which support the welder are set at the required 6 degree angle as required for proper carbon arc welding.

Slabs up to 42-inches wide, regardless of their length, are set up in troughs, which troughs are constructed so that they also have the necessary 6 degree angle. Slabs over 42-inches are set up in a specially designed, reinforced concrete pit. The pit is in the center of the rails on which the gantry moves and there are two troughs on one end and one on the other end of the pit, so placed that the gantry can be positioned over them.

This arrangement enables us to set up slabs in either the pit or the troughs, while welding is being done elsewhere in the line. When we first went into operation, we were only able to operate 23 per cent actual welding per turn; this has now been improved to the point where we often operated at 50 per
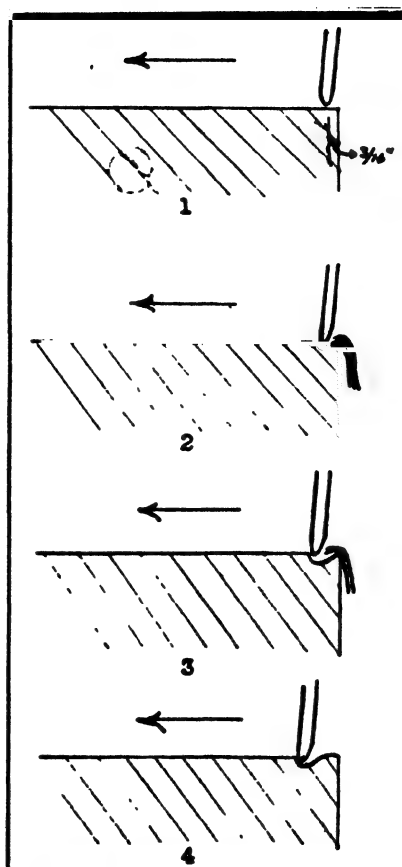
Fig. 4. Starting weld procedure.

cent of the full turn. The ultimate actual welding time expressed in percentage is probably about 60 per cent because the runs are relatively short and, therefore, there must be numerous stoppages, resettings, and commencements at the start of each weld, one does not proceed at the usual speed, (See Fig. 4).

Subsidiary equipment has also been required and secured from time to time. Under practical operating conditions, it is virtually impossible to expect a perfect fit-up in all cases, (See Fig. 5), so that certain jigs and drawjacks are employed; further remarks will be made regarding fit-up later on. Rather than try to hold the components together mechanically, some hand welding is advisable; therefore, we found it advisable to secure a third 400-ampere generator. Before we had the third generator, we used one of the two original machines, but this held up the arc welder. Certain heating equipment of a simple and inexpensive nature has been secured to ensure freedom from moisture within the assembly; it has been found that if there is any moisture, steam is created during heating and this creates a further strain on the weld —when the rolling stresses are already very high.

As stated heretofore, the power for the arc welder was originally supplied by two 400-ampere generators. As we became more familiar with the technique and in view of the occasional fractures of the welds during rolling, we decided to put more power through the machine. We, therefore, secured a 600-ampere generator, which is hooked with one 400-ampere machine into a fixed circuit with the welder; in addition, another 400-ampere generator is so set up that it can be cut into the circuit and thus provide 1400-amperes. The power arrangement is indicated in Fig. 6, and the relationship of the depth of the welds to the amperage may be observed in Table IV. The current is carried to the welding head by three 00 welding cables and the current used is from 800- to 1500-amperes. The three cables carrying the current are connected to a lug back from the heat of the arc and the current is carried from there to the twin tornadoes by four 00 cables which can be easily replaced. It has been found that connecting two of these cables to the twin tornado's water inlet connection and two of them to the carbon tornado's water outlet connecion, gives the proper arc direction at the high current used by us.

When we increased the amperage through the boots to more than 1,000-amperes, we began to burn out the magnetic boot in some cases and the carbon-carrying boot in other cases. It was, therefore, necessary to augment the cooling capacity of the system; the manner in which this was worked out may be observed in detail in Table III. We feel that this redesign of the cooling system has particular merit as it would soon have proven uneconomical to operate the arc welder over 1,000-amperes, while at the same time, we would have encountered a limitation in our arc welding which would have greatly reduced its over-all benefit.

Because this redesign of the cooling system might be of value to others, we would comment as follows:

The water cooling system is the most critical item to be handled in automatic carbon arc welding. The current carried to the head by three 00 cables, and to the boots by four 00 cables is then carried by thin walled copper tubing to the carbon. In order to prevent the tubing from melting, water is pumped through continuously, (See Fig. 7). If high current is used, it is advisable to have a separate feed and return line to each boot. There are vacuum switches in the water return lines which are designed to break the arc immediately if the water stops for any reason. The water system is a closed system pumping from a 42-gallon tank and returning to a 55-gallon

drum. The centrifugal pump is placed below the top of the drum so that it is primed at all times. When operating continuously at high amperage, there is a build-up of heat in the water with approximately 100-gallons in a closed system. Each time the water goes through the system while an arc is struck, it picks up more heat than can be dissipated between passes. In order to overcome this condition, it was necessary to either run fresh water through the system all the time, which would be expensive, or make some provision for cooling the water in the return lines. This problem was overcome by running the return lines into an old-type brass tube automobile radiator. The outlet from the radiator was connected to the 55-gallon drum. A ventilator type fan was connected to the radiator so that air was blown through the radiator. This arrangement cooled the water so that it did not become hotter than 120 degrees F. in the hottest weather and using high current.

The water switches are most important, as, if they do not shut the machine down immediately when the water stops circulating at the proper speed, either boot may be ruined. These switches should be set with a good margin of safety. The switches should be placed at the highest point in the line to eliminate any back pressure. And it proved best in our case to make the highest point the turn where the return lines went into the radiator. The water switches were placed on a panel above the radiator, and hose longer than the return line was used to carry the water from the vacuum exhaust to the radiator. The water lines should be made of hose which has a firm rubber lining inside and one or two ply of reinforcing, such as beer hose. Do not use hose with soft rubber lining such as oxy-acetelyne hose or hose with no textile reinforcing.

Let us now consider actual welding with the above-described equipment; a guidance chart, Table III, has been prepared and is enclosed hereinafter. The arc voltage, amperage, and welding speed per minute for each of the sizes has been established by actual practice, and in each case has been found to yield the strongest and most ductile weld at the rolling temperature. This chart is indicative to the extent that numerous variations are possible; not all thicknesses have been included; where the thicknesses are different from those shown, the settings will be proportional within the ranges indicated for each of the settings.

This chart has been set up on the basis of the thicknesses of the assemblies in ascending order; this is not necessarily the predominant factor. The depth, or thickness, of the spacer bar shall pre-determine the character of the weld desired; the spacer bar thickness or depth is the underlined figure in Column IV. It is not true that the relationship between the insert thickness and the backing thickness remains constant. For example, we have shown the use of a ½-inch thick insert with a 2-inch thick backing; actually, the insert might be as little as ⅛-inch in thickness or as much as 1-inch, depending upon the percentage of cladding desired on the finished plate. Incidentally, the total slab thickness is computed by adding two times the figure in the second column to two times the figure in the third column.

At the bottom of the chart, there is an exception in the order. You will note that in all other cases two beads are made on each side of the assembly; in other words, you make one weld down one side of the spacer bar and another weld down the other side of it. Or, to put it otherwise, refer to Fig. 1-B, which will disclose that there are two seams on each side of every assembly; each of these seams must be welded. But in the case of assemblies where the spacer bar is ½-inch wide or less, it has been found that one single arc weld may be made down along the center of the spacer bar which

Table III—Guidance Charts*—Carbon Arc Welding
(Presuming Proper Fit-Up)

Total Thickness	Backing Thickness	Insert Thickness	Spacer Bar	Slab Weight Lbs.	Arc Voltage	Amperage	Welding Speed per Minute	Beads per Side	Beads per Seam	Remarks
5"	2"	½"	¾" x 1"	350–5,000	35–37	875–925	5" –5½"	2	1	Use filler wire generously — hold down flux.
7½"	3"	¾"	1" x 1½"	2,000–7,500	37–39	925–975	4½"–5"	2	1	Use filler wire generously — sufficient flux to cover arc.
7½"	3"	½"	1" x 1"	1,800–7,000	39–41	975 1,025	4½"–5"	2	1	Use filler wire generously — sufficient flux to cover arc.
10"	4"	1"	1¼" x 2"	2,500–20,000	39–41	1,025–1,075	3" –3½"	2	1	Use filler wire and flux generously — Keep arc and pool well covered.
12½"	5"	1¼"	1½" x 2½"	3,500–23,500	40–42	1,050–1,100	2¼"–3¼"	2	1	Use filler wire and flux generously — Keep arc and pool covered.
18"	7"	2"	2" x 4"	8,000–25,000	41–42	1,100–1,150	2½"–3"	2	1	Use filler wire and flux generously — Keep arc and pool covered.
25"	10"	2½"	2" x 5"	11,000–25,000	42–43	1,150–1,200	2½"–3"	2	1	Use filler wire and flux generously — Keep arc and pool covered
3"	1¼"	¼"	1" x ½"	up to 3,000	37–39	900–1,000	4½"–5"	1	1	Set arc on center of spacer bar. Not too much wire but plenty of flux

*Intermediate settings, etc., will be proportionate. Generally speaking, the depth of the spacer bar shall be the determining factor in the settings.
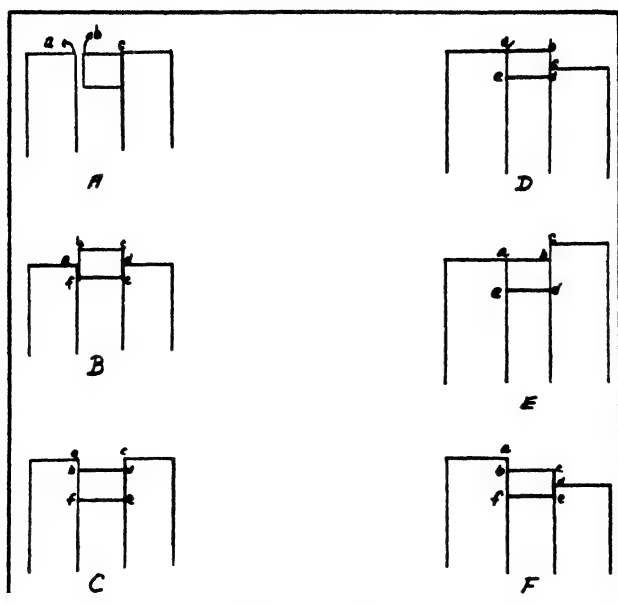
Fig. 5. Fit-ups.

yields a sufficiently strong weld for heating and rolling. Thus, in spite of the fact that there are two seams on relatively thin assemblies, one bead per side suffices.

Reference to Fig. 8 discloses the recommended positioning of the carbon in the molten pool. This position is, of course, a function of voltage, amperage, and speed; it is a practical means, and a good one, of verifying the correctness of the settings. When the carbon is too far behind the front of the crater, we found that porosity existed. Such porosity would be undesirable in any application of carbon arc welding.

In our particular application, due to the presence primarily of the separating compounds, we were troubled with moisture. Appreciable heat is generated during welding, and we found that we not only generated steam which caused trouble in rolling, but the weld itself tended to be less solid. This difficulty has been overcome almost entirely by pre-heating the slabs at 120 degrees to 130 degrees F. for approximately 24 hours. Our work has indicated that carbon arc welding is very sensitive to moisture, and it is suggested that anyone using such equipment should guard against moisture in any form, especially in winter or rainy weather.

The original practice was to hand weld starting and stopping lugs on either end of the run. It was subsequently discovered that this is not necessary if one proceeds as per Fig. 4. By setting the carbon $\frac{3}{16}$-inch from the edge of the slab, you create a pool which does not wash down the side. As soon as a crater of the proper depth is formed, proceed at the prescribed speed. When you get to the end of the run, the machine may be halted momentarily about $\frac{3}{16}$-inch from the end, which will likewise produce a thorough weld. If a crater exists after the cooling, clean off the slag and fill in by hand welding.

The accuracy of the fit-up of the various components will obviously have an important bearing upon the welding procedure. Our experience would

indicate that a tolerance of 1/16-inch may be safely applied to any point of fitment. Fig. 5 shows six misfits.

Where a gap exists as indicated in "A", we move the carbon over onto the backing slab about 3/16-inch from the open seam. Using relatively low amperage, low voltage and ordinary speed, we make a light weld which closes up the gap. Another advantage of so proceeding is that very little, if any, molten metal falls down between the inserts (that would be undesirable) because only the cooler portion of the pool enters the gap and it freezes immediately. After we have closed the gap in this fashion, we go back and make a regular weld.

It should be mentioned here that the skill of the operator plays an important part in handling gaps. A gap is not necessarily of uniform width; it usually develops because of a bow in one or more of the components. If the welder is skilled, he can guide the machine so that it will maintain the 3/16-inch distance from the gap along the entire line of welding. An inexperienced welder may get too close to the gap and cause molten metal to fall down into the slab.

Figure "B" is probably the worst condition that can exist, because the effective depth of the bar is decreased. Generally speaking, the thickness of the spacer bar is such that the arc weld will almost penetrate through its entire thickness. If the slab is not too heavy nor too large, or if the projection is not more than 1/8-inch, we proceed with the welds in much the usual manner except that we decrease the voltage and the amperage. Obviously, this is done to reduce the penetration, and the actual amount of reduction of amperage and voltage will be dependent upon how much penetration is desired. Figures "C", "D", and "E" are all handled in a similar manner. In each case, there is one reasonably satisfactory or perfect abutment. Then the second weld is made in accordance with the remarks with regard to "B". In the
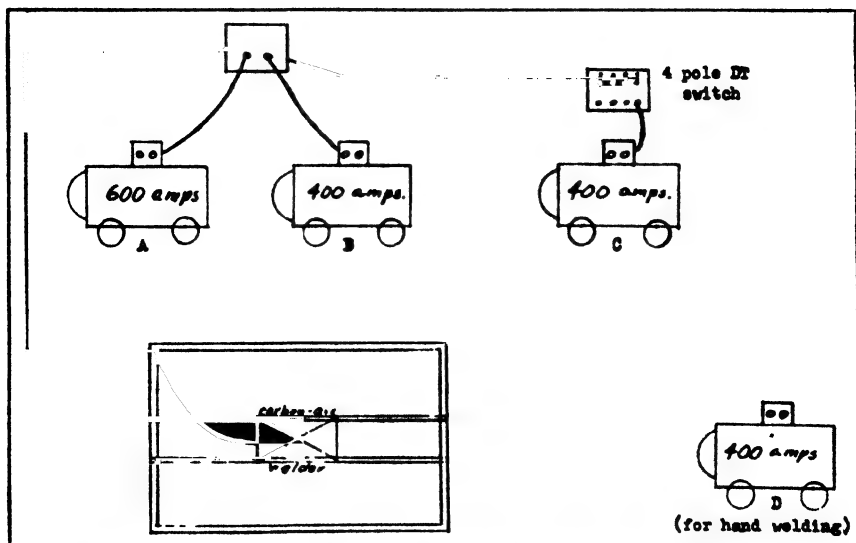
Fig. 6. General arrangement. Generators A and B are used up to 1000-amperes. Generators A, B and C are used for loads in excess of 1000-amperes. Generators A and B may be operated independently of C; C may be cut out at the pole switch. The exciter in B is used for automatic excitation regardless of whether 2 or 3 generators are connected. The exciter in A is used for tractor and automatic welder head drive.
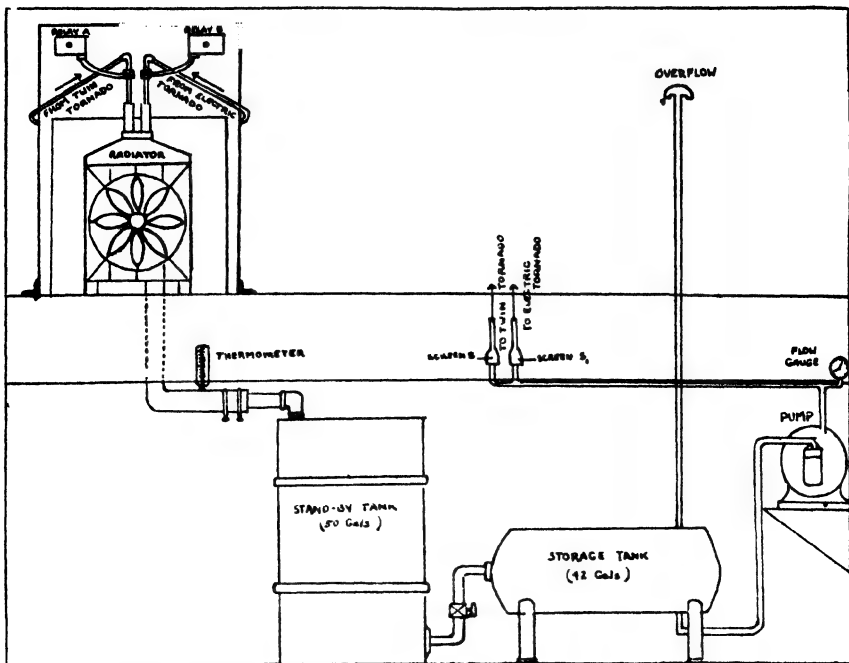
Fig. 7. Special arrangement to cool boots up to 1400-amperes.

case of "F", weld the highest abutment first, following the same procedure as outlined for "B". Then weld the lower abutment, again following the same procedure as for "B".

Before pre-heating and welding, all slabs are carefully examined so that if there is any misfitting beyond a reasonable maximum (generally speaking, about 3/16-inch), they are sent back for correction within the prescribed limits.

In some instances, the welding heat may cause a slight gap on the unwelded sides, even though the components may be very well tacked together. If this gap is between 1/16- and 1/8-inch wide, we have found that a good weld can be effected by simply increasing the voltage by two volts. If the gap exceeds 1/8-inch, use the procedure as described for Fig. 5-A.

Anyone who has used carbon arc welding equipment has probably encountered "arc blow", in other words, an erratic or a spitting welding action. In our case, we have found that we can correct this by increasing the forward speed of the tractor. Or we can guide the filler wire nearer to the arc magnet side of the boot, at the same time lowering it to within 1/8-inch of the slab.

Table IV—Penetration of Arc Welds Relative to Amperage

Amperage	Penetration
800-Amperes	1/2-inch penetration
900-Amperes	5/8-inch penetration
1,000-Amperes	3/4-inch penetration
1,200-Amperes	13/16-inch penetration
1,400-Amperes	7/8-inch penetration

For a given amperage, the penetration remains substantially constant regardless of the rate of speed. However, at a relatively high speed, the cross-sectional area of the weld is V-shaped and comparatively flat on top, rising only slightly above the plane of the two pieces being welded. If the speed is decreased below normal, the cross-sectional area of the weld is increased to a U-shape.

For our work, the best weld is approximately twice as wide at the top as it is deep.
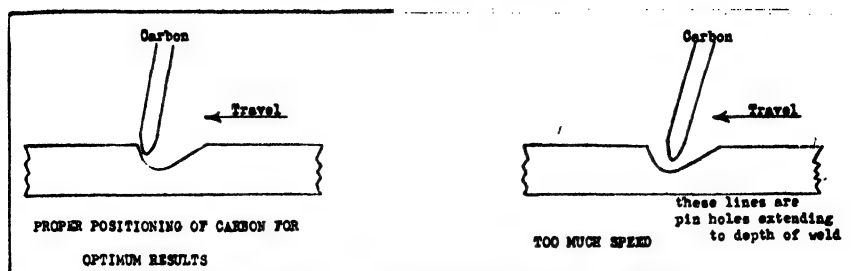
Fig. 8. Proper and improper positioning of carbon.

Although it does not occur often, we sometimes encounter cracks in the welds. We are more apt to encounter this condition when using special analyses of backing steels; the higher the carbon and/or the higher the alloy content, the more the tendency will be to cracking. In such cases, we weld the slab completely all the way around, then we go back and re-weld, after cleaning off the flux, but we shut off all filler wire, retain the usual speed and voltage but reduce the amperage by 50- to 75-amperes. If, when we start to re-weld, we encounter re-cracking, allow the slab to cool for 24 hours and then follow the re-welding procedure outlined above. If a crack does not extend the full length of the seam, weld the full length of that seam anyway. Generally speaking, when you cannot hold your hand on a slab, do not weld on it.

On welds exceeding 950-amperes, it has been found essential to check each individual carbon. The carbon should be cleaned with emery cloth so that it fits perfectly in the boot. Otherwise, the high current may cause the carbon to stick which will break either the carbon or sometimes the spindle.

Needless to say, we have found it advisable to keep the machine thoroughly clean. If we do not do so, we have found by experience that our efficiency is noticeably reduced; so each welder cleans the machine after his turn.

After the assembly comes off the arc welder, it is carefully examined for any fissures or craters. Short fissures, two to three inches, may be hand welded; likewise, craters may be corrected by hand welding. In some cases, where we expect to effect an unusually wide plate by extensive cross rolling, we will hand weld strips around the edges of the assembly at a 90 degree angle to the carbon arc welds. It is recommended that this procedure be followed by anyone starting to use such a system until they become fully conversant with the technique.

This carbon arc welder is so arranged that it can be taken out of the gantry and used for welding flat plates or pipe. In other words, it is an all-purpose machine.

Such work of this nature as we have done was found to be entirely satisfactory. One of the questions that often arises regarding carbon arc welding is "What is the analysis of the finished weld as compared to the components?" Such an analysis is presented herewith:—

	Parent Metal	Weld Metal
Carbon	.19	.15
Manganese	.47	.49
Phosphorus	.013	.013
Sulphur	.032	.032
Silicon	.040	.040

In conclusion, may we say that the carbon arc welding has fulfilled our expectations to our entire satisfaction, in fact, in so far as increase in yield is concerned, it has exceeded our expectations. The costs per lineal foot in this application of carbon arc welding probably do not compare particularly well with the usual adaptation of the process; we feel this may be explained by the fact that our runs are comparatively short, though numerous; and at all times, we are striving to effect maximum penetration on heavy sections. However, it is entirely clear that the present lineal foot costs are very favorable indeed for the carbon arc welder, as compared to the previous method. We are also satisfied that the character of the weld meets our requirements to a greater extent than did the previous method.

We summarize herewith the various items of conservation effected:—(a) Less weight per slab by an average of 10 per cent; (b) More slabs welded per turn; (c) Much less weld metal; (d) The fundamental conservation of alloy steel by making it in clad form by this process.

Chapter XXIX—Arc Welding in the Manufacture of Mowers

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Subject Matter: The design, construction and cost of arc welded heavy-duty power mowers. Arc welding this unit decreased the weight, eliminated loosening of parts, eliminated costly and critical materials and produced a mower which could be operated at high speeds for long periods of time without need of repair. Unique plug welding of spline and press fits decreased fabrication cost and eliminated wear and loosening of parts in service. Plug welding of malleable iron hubs to steel shafts eliminated expensive steel castings and forgings. The use of plug welding for many parts on this unit resulted in savings of between 4% and 40% as compared with other methods.

In the mass production of industrial or farm machinery, arc welding is subject to the keen competition of all other methods of manufacture. The parts are usually small enough to be made by various processes and quantities are sufficient to allow for amortization of patterns, dies or equipment that might be required by any one of several methods available.

Where arc welding has been used therefore in the mowing machine shown in Figs. 1 to 5, it has been because of lower cost, lighter weight and greater ability to withstand vibration and shock loads than any other type of construction which we have tried.

Previous Construction—Before high speed and light weight became the order of the day for modern tractor equipment, the selection of materials were largely a matter of engineering convenience.

Construction was of cast iron, hot rolled low carbon steel, with braces and framework made of flat bars or structural steel, and bolted together. The shafts were usually supported on plain bearings in a cast iron frame or in cast iron brackets bolted to the steel frame. The result was that the

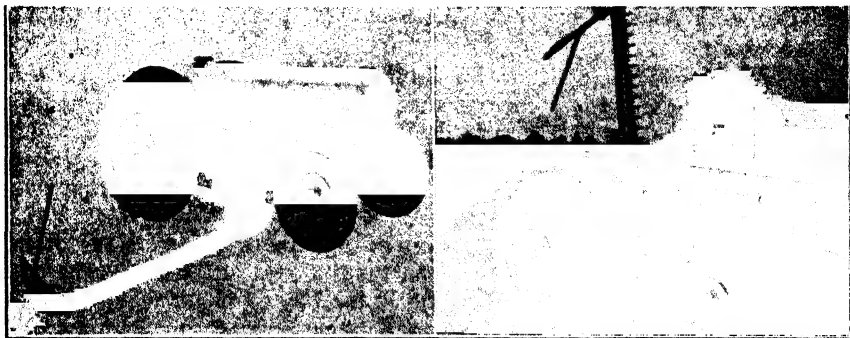



Fig. 1a. (left). Mower with blade in cutting position. Fig. 1b. (right). Mower with blade in running position.

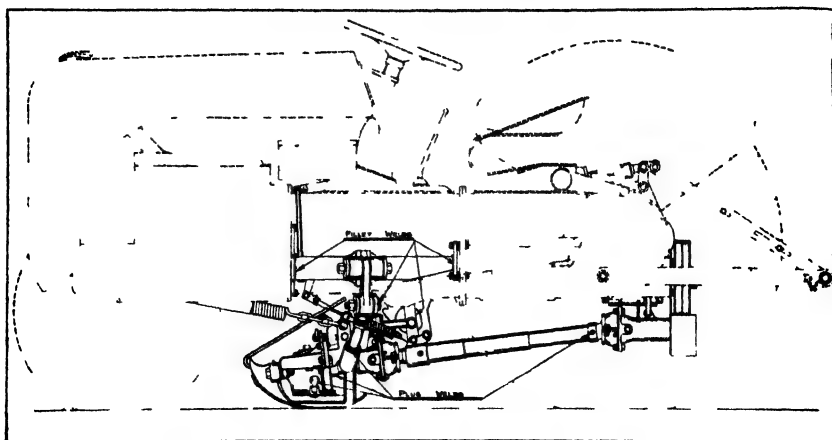



Fig. 2. Heavy-duty mower left side view.

weight was high, and bolts would come loose. We have eliminated this as much as possible by arc welding and the use of high grade materials.

Parts that rotated with shafts were attached either by a cross pin or rivet, a set screw, a key or by means of a spline. The method depended somewhat upon the torque transmitted. None were as sure a method of locking the part to the shaft securely as the arc welding method here described.

Previous Mowers Slow in Speed—The reciprocating sickle-type of mowing machine was pretty well standardized as a horse-drawn implement along general lines indicated above before the tractor era. The slow speed of horses permitted a slow sickle speed with little vibration Until recently the tractor mower has been merely an adaptation of the horse drawn mower by driving it from the power take-off shaft (projecting from the rear of the tractor) instead of from the ground wheels. The older methods and materials do not stand up with the high speeds now available

Modern Mowers Must Run at High Speeds—Both farm and industrial tractors of the day are light-weight machine mounted on rubber tires or special steel wheels which will permit relatively high speeds By designing a new mower to resist wear and tear of high speeds we have enabled operators to make full use of the available speed in their tractors Our mowers are now operating as fast as 11-miles per hour instead of 2- to 4-miles per hour with older types But increased speed is only part of the picture.

Heavy Duty Mowers Used for Longer Periods—The mower on the average farm is used only a few days a year. If two or three crops of hay are cut a few more days use are added But in highway and airfield mowing, for which our machines are designed, the work extends over the entire growing season of about 4 months. Often the work requires mowing two shifts per day.

Likewise in the south and west part of the country mowers are often used to cut irrigated alfalfa eight or ten times a year and by the time the last field of a large farm is cut the first field is ready to be cut again. In this case the mower is in almost daily use for about eight months of the year, and other tractors are kept for the other farm work.

Vibration—The sickle speed must of course be increased in proportion

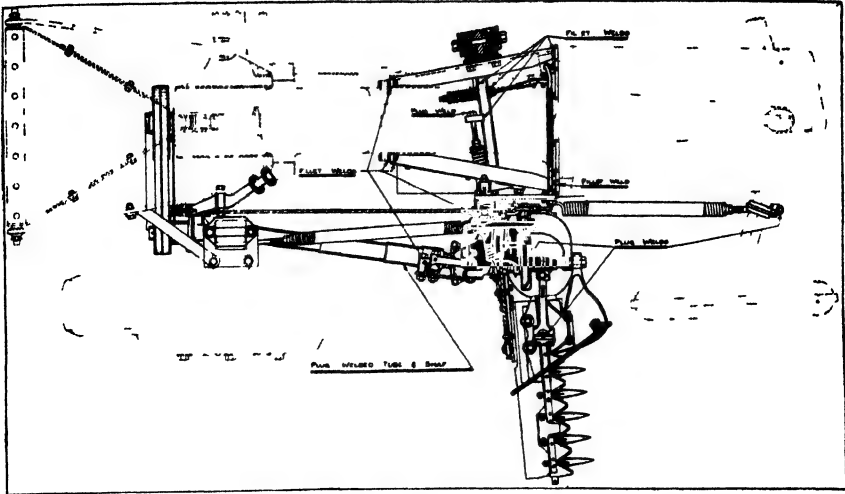



Fig. 3. Heavy-duty mower top view.

to forward travel. It has not been possible to reduce the weight of the sickle however as compared with that of the horse-drawn type mower and so vibration is increased

A six-foot sickle weighs 9½-pounds and has a 3-inch stroke When mowing at 5-miles per hour in second gear or 11-miles per hour in high the mower flywheel runs at 1422 revolutions per minute or 2844 cutting strokes of the sickle per minute Although this is over twice as fast as the horse-drawn mower, the arc welding of various parts permits this mower to stand up and also operate on heavier schedules

Roadside Mowing Requires Ruggedness—Besides higher vibration loads there is the increased magnitude of shock loads to contend with in roadside

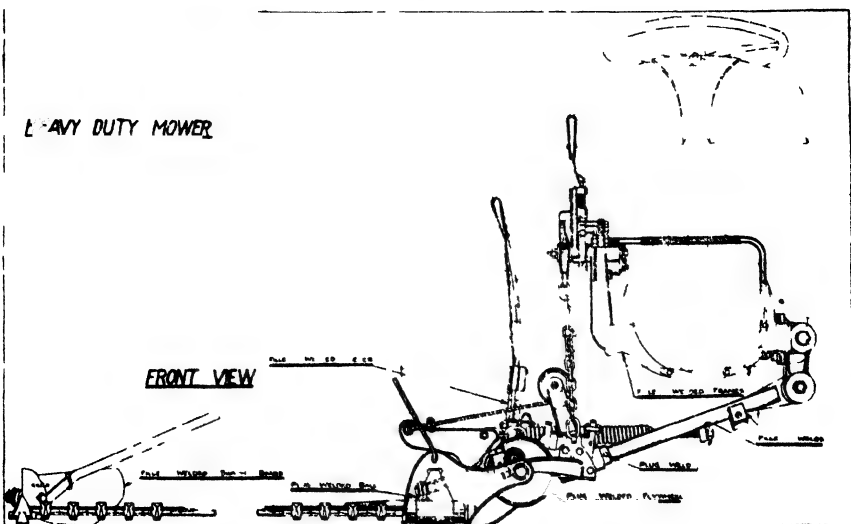



Fig. 4. Heavy-duty mower front view.

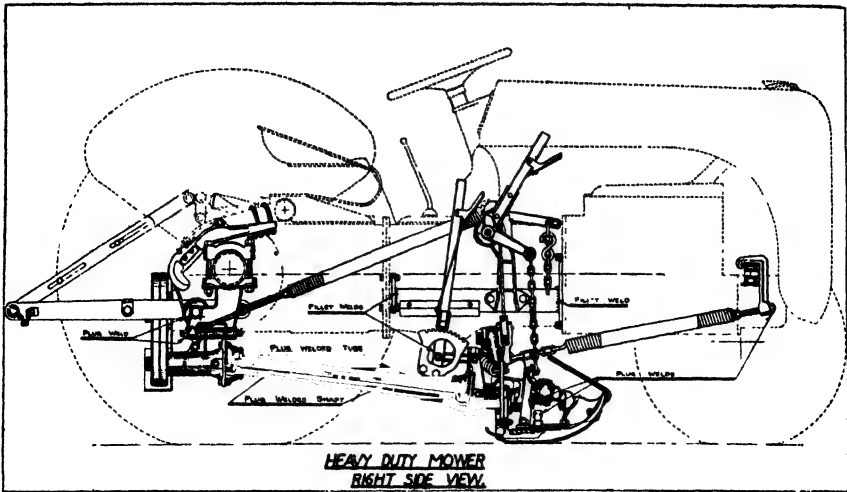



Fig. 5. Heavy-duty mower right side view.

mowing. This is due to frequently met obstruction and uneven ground. Brush and small saplings are cut down. Wires, stones, tin cans and stakes hidden by the grass are frequently encountered and the mower must cut into or through them. If the resistance is too great a safety release device allows the bar to swing backward and at the same time stops the tractor by disengaging the clutch. This punishment is taken care of by using a sickle that is reinforced and has extra thick sickle sections and a forged and heat-treated head with a hardened ball driving connection arc welded in place.

Plug Type Arc Welding Favored—Our experience shows a plug type of weld is made quicker than other types such as butt, edge, fillet or lap welds. Two plug welds in holes $^{11}/_{16}$-inch diameter give sufficient strength in most parts of the mowing machine. These welds require only 15- to 30-seconds each. Consequently we are using this method wherever possible. It has also been found that malleable iron can be welded to steel successfully by this method. This has been a life-saver as we formerly used steel castings entirely when arc welding castings to steel but steel castings are now difficult to obtain even with the best priority ratings.

Although heating malleable to the fusing point tends to turn it back to white iron, actual checks of these welds shows the metal hardens only slightly. This is shown in Fig. 6, which is a Rockwell hardness test taken at close intervals across several such welds. Note that the hardness of the malleable iron, far enough from the weld to not be heated, is approximately B-65-B-70 Rockwell. The hardest spot checked is B-106 Rockwell which corresponds to approximately 285 Brinell. This is far below the 401 Brinell which is the average hardness of these castings in their original white iron state. Besides, a plug weld, if not too near the edge of the casting is surrounded by sufficient metal in the original malleable condition to support it, and in actual use we have no trouble from welding malleable to steel in this way. We do not, however, attempt to weld malleable to steel where the weld would be subjected to tension. Nor do we attempt to weld malleable iron to malleable iron.

Welds are made in our plant by pressing the steel part into a hub of

the malleable casting with a light press fit and then plug welding through cross holes in the hub only. 5/32-inch electrodes are ordinarily used and 1/8-inch diameter when less heat is desired. Peening the weld before cooling is in most cases not necessary. Loads carried through the welded joint subjects the metal at the surface of the shaft to shear stress. Loads transmitted to or from the casting causes compression stresses at the weld.

The first year we welded malleable iron to steel in production it was only put through on two parts of the mower even though field tests had shown it to be satisfactory. This gave no trouble or failures and so the second year we plug-welded several more malleables by the specific method described and are now using the method also on other models not described in this paper.

Description of Mower—The mower which is built with the arc welding described, is mounted on the side of the tractor where it is in full view of the operator. The drive is from the rear power take-off shaft by V-belts to a jackshaft (mounted under the axle) and from there to the mower crankshaft through an enclosed propeller shaft with universal joint at each end.

The mower mechanism is supported by a heavy crossbar which passes under the transmission and is hinged at the left side of the tractor. The telescoping propeller shaft housing holds the mower bar in alignment but does not take any thrust in normal cutting. A heavy spring extending to the front axle keeps the bar in normal position but permits it to swing backward when an obstacle is encountered as both the propeller shaft and the propeller shaft tube can telescope. The mower crankshaft is concentric

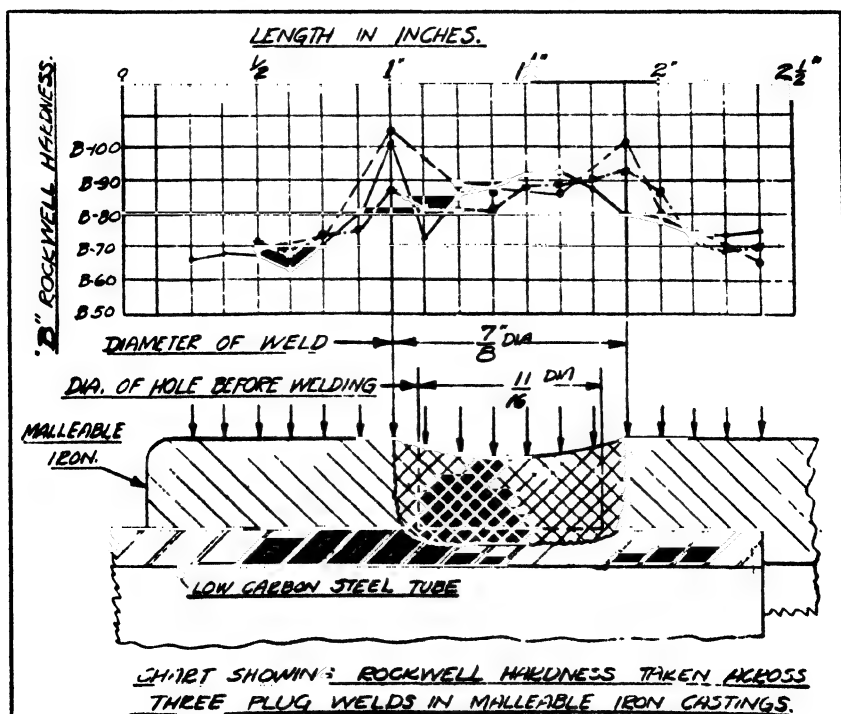



Fig. 6. Rockwell hardness across plug welds in malleable iron castings.

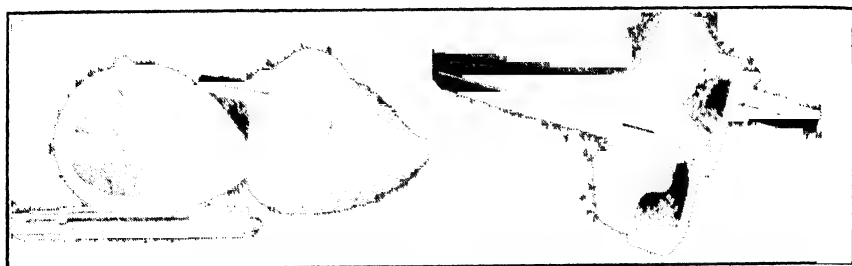



Fig. 7. (left). First design of counterbalanced wheel and shaft. Fig. 8. (right). Section cut for tests.

with the hinge point of the bar which allows the bar to cut up or down the side of a ditch or bank at any angle The weight is partially balanced by springs to prevent digging into the ground and the mower can be folded up and lifted off the ground at the inner end simultaneously by means of a hydraulic cylinder connected to the mower by a flexible cable The mower is mounted on two welded steel side members attached to the transmission These are necessary as the tractor is of the frameless type The cross bar of the mower is attached to the frame at a rubber bushed bracket which greatly reduces vibration on the tractor itself The weight of the 6-foot mower is 453-pounds which is just half the weight of trailer type horse and tractor mowers which weigh from 825- to 980-pounds

Social Advantages—From the standpoint of safety it is advisable to have clear vision on roadsides to reduce the danger of motorists hitting children or animals Besides, the destruction of noxious weeds by mowing greater mileage of roadsides is of great value to farmers

The social advantage of arc welding this mower rests in the higher speed which it permits This results in greater acreage, or mileage of roadsides cut per year by this mower than would be possible otherwise

Welding Practice for Mower—Following are detailed descriptions of parts of the above mower which we are producing cheaper and better by arc welding Some of these represent only a small saving per piece but are included, as the comparatively large quantity multiplies these savings to sizable figures

The net savings with the arc welding as compared with other manufacturing methods tried are given and totals summed up at the end of the paper

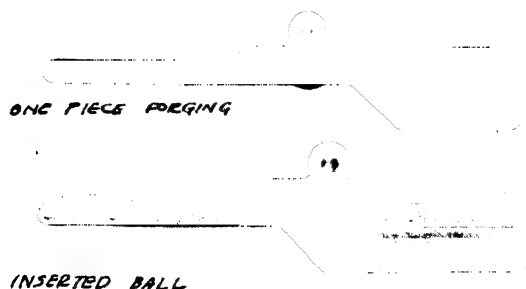



Fig. 9. Head as first forged with ball integral (top) and changed for pressing ball into position (bottom).

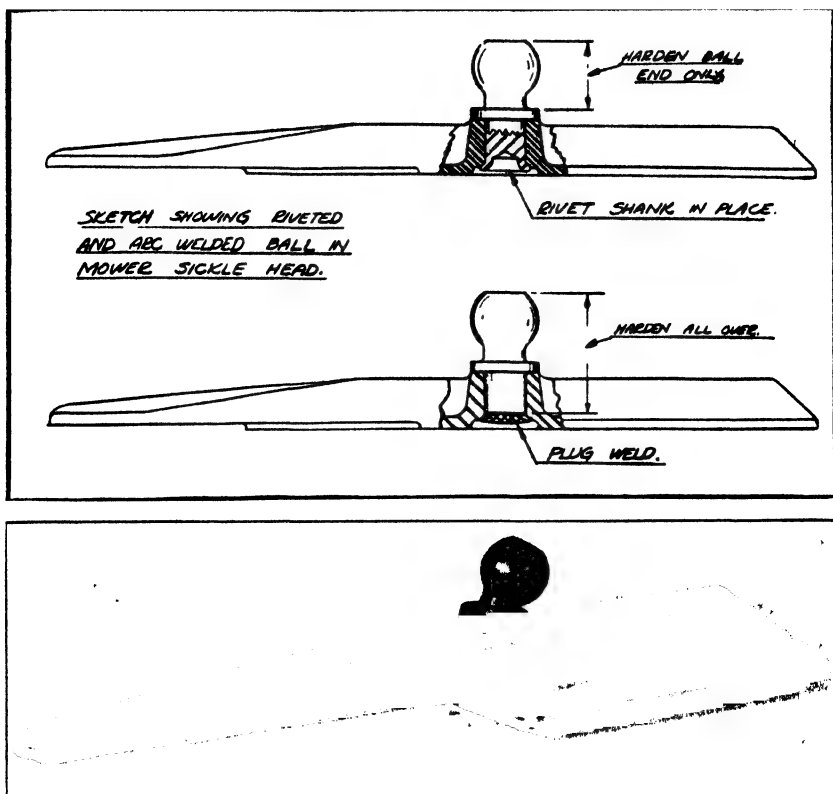



Fig. 10. (above). Ball riveted and welded in place on sickle head. Fig. 11. (below). Arc welded ball with short shank after hammer test.

(A.), Crankshaft—This consists of a $7\frac{1}{4}$-inch diameter malleable iron counterbalanced wheel weighing $8\frac{1}{2}$-pounds and a $1\frac{3}{16}$-inch diameter heat treated S.A.E. 4140 steel shaft.

In the first design shown at the left in Fig. 7, the wheel and shaft were splined together and assembled with a light press fit.

The load from the reciprocating knife is applied at the crank pin which is overhung and thus tends to rock the wheel on the shaft first one way and then the other. In some severe mowing conditions the ends of the malleable iron hub were thus subjected to compressive loads beyond the elastic limit and the hole eventually was worn bell-mouthed at each end. The cross-pin prevented the wheel from coming off but did not contribute to holding the wheel tight. This problem could probably have been solved by using a hardened forged steel wheel but the cost was prohibitive even if material could have been obtained. Since it was not necessary to have the flywheel and shaft separable for assembly purposes it was decided to use arc welding as shown at the right on the cut.

A $\frac{5}{8}$-inch diameter hole is drilled clear through the wheel hub before pressing it on to the hardened and ground shaft. This provides two plug welds. Several thousand of these have been made without a single one loosening up as far as we have been able to find out, as the positive bond between the two pieces prevents loosening. The smooth shaft permitted by

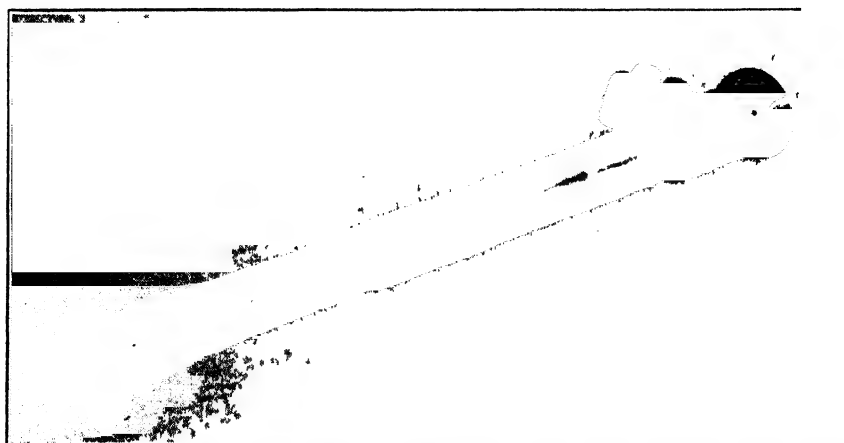
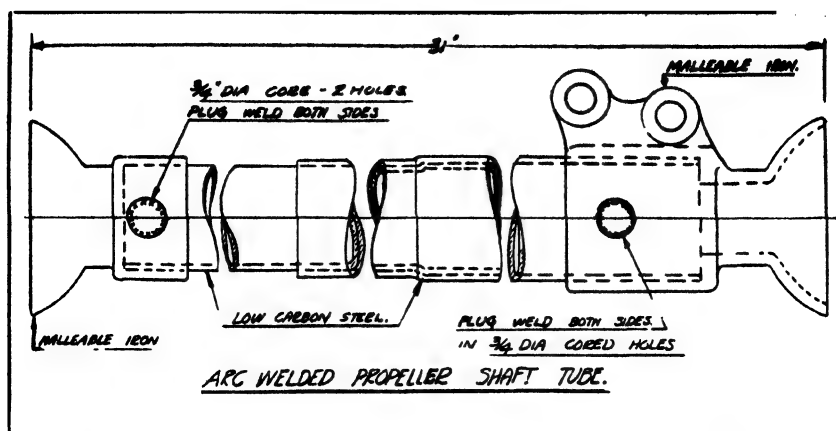



Fig. 12, (above). Sketch of arc welded propeller shaft tube. Fig. 13, (below). Arc welded propeller shaft tube.

welding also offers much greater area in contact with the casting than with splines which do not fit at the root diameter but only on the top and sides. This increased contact area is also a reason for the welded crankshafts holding tight.

The section in Fig. 8 has been cut so as to go partially into the weld to facilitate checking around the weld by Rockwell and Magnaflux tests. The remaining spot is a slightly lower crater. Small cracks sometimes are present in this crater but do not extend through the edge of the weld and so do not reduce its strength appreciably.

The welding replaces the following operations and a special pin.

Broach flywheel
Hob Shaft
Grind O.D. Splines (spline slightly smaller than adjacent part of shaft)
Assemble Cross Pin
Cost of Cross Pin

This results in a saving of 7 percent of cost of crankshaft.

(B.), Sickle Head Ball—This is a 1045 S.A.E. steel forging to which the

Fig. 14. Sheave stud.

sickle is attached. A hardened steel ball on the sickle head is connected to the ball socket of the pitman rod. One spare sickle is provided with each mower and where tractors do not come back to the garage every night several spare sickles are provided so the operator can insert a sharp one whenever necessary. Consequently every effort is made to keep the cost of the sickle low so as to encourage customers to have several sharpened sickles available. This reduces down time as the sickles are easily changed in the field.

The head was first forged with the ball integral (as shown in the upper view of Fig. 9) and heat-treated to 269 Brinell. This was too soft to prevent wear of the ball but increasing the hardness caused breakage at the tip end of the head where attached to the sickle back. Therefore the 1¼-inch diameter ball was made a separate screw machine part carburized on the ball end only by liquid process, and pressed into the sickle head and riveted over on the bottom in a punch press as shown in the lower view. The riveting required the end of the ball insert be left soft and the cost of this in the heat treat department was twice as great as if it had been carburized and hardened all over because it required individual handling of the balls, setting them in racks so they could be immersed in the carburizing bath to the depth specified only. We therefore tried arc welding balls that had been hardened all over as shown in Fig. 10.

Welding onto the carburized ball was expected to cause a certain amount

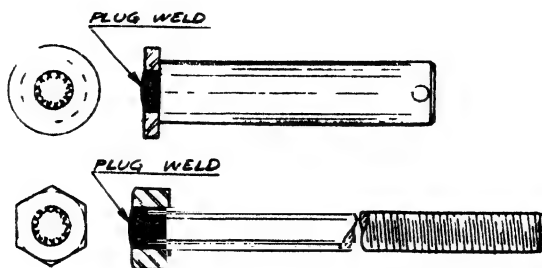



Fig. 15. Arc welded pin and adjusting screw.

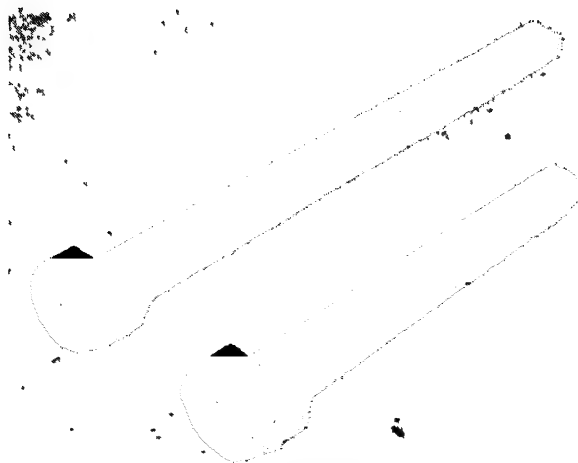



Fig. 16. Adjusting screws.

of brittleness in the weld because of the high carbon content of the .020-inch carburized case on the ball shank. Welding time was 16-seconds. Tests were made by clamping the heads in a heavy vise and hitting the ball with a 4-pound hammer, (See Fig. 11). With the shank made the same length as that of the riveted ball a weld of sufficient area was obtained which exceeded the strength of the ball as hammer tests destroyed the ball and the forging without breaking the weld. Consequently the shank of the ball was shortened to reduce weight and cost of the ball further. In this case it was possible to break the weld, but only after bending the neck of the ball and destroying the boss of the forging with blows which elongated the hole 20 percent. This produced a leverage on the weld which eventually pulled it apart. This is far in excess of loads occurring in actual service as field tests later proved the welded short shank ball OK.

Cost—riveted ball considered 100 percent for comparison.

Riveted Ball	Percent
Material	15.6
Automatic Screw Machine	5.9
Drill Hole in Shank	4 7
Carborize and harden ball end only	27.2
Centerless Grind Shank	3.8
Assemble and Rivet	4.7
Burden	38.1
Total	100.0
Welded Ball	
Material	13 9
Automatic	5.9
Carburize and harden all over	14.0
Centerless Grind Shank	3 9
Assemble and Weld	7.0
Burden	33.0
Total	77.7

Savings per pair due to arc welding (2 Req'd. per mower)

Steel saved = 10% Cost saved = 22%

This does not include cost saved by omitting chamfer at bottom of hole in knife head which is necessary for riveting but not welding.

(C.), Propeller Shaft Tube—This is shown in Figs. 12 and 13 and consists of two telescoping 1/8-inch thick steel tubes with malleable iron bell housings plug welded at one end of each tube. The tubes have swadged shoulders which mate and thus act as stops. When the mower strikes a stump the tubes telescope and when free of the obstruction the pull spring jerks the tubes up to the stop shoulders again. This tends to pull the two bell castings off the tubes and thus tends to shear the plug welds, two of which are used at each end.

The tube assembly is also subjected to severe bending loads in service.

Previous to adopting the plug welded method, the tubes were brazed at the end of the hub of the castings where the tubes enter. This was not satisfactory as the tube became annealed thereby. Since it is a cold drawn seamless tube it was weakened to the extent of causing it to bend in some cases. With plug arc welding the tubes are obviously annealed only well inside the ends of the castings which provide plenty of reinforcing stiffness. In testing a mower with one of the plug welded tubes, the mower was run against solid obstructions. The automatic clutch release had been disconnected so that after the bar swung back to the limit stops in the tube assembly, the tractor wheels kept pushing ahead. This rotated the whole tractor around the obstruction, skidding the front wheels sideways but not bending the plug welded tube assembly.

Fig. 17. (above). Left hand frame with welds shown by white paint. Fig. 18. (below). Left hand frame with welds unretouched.

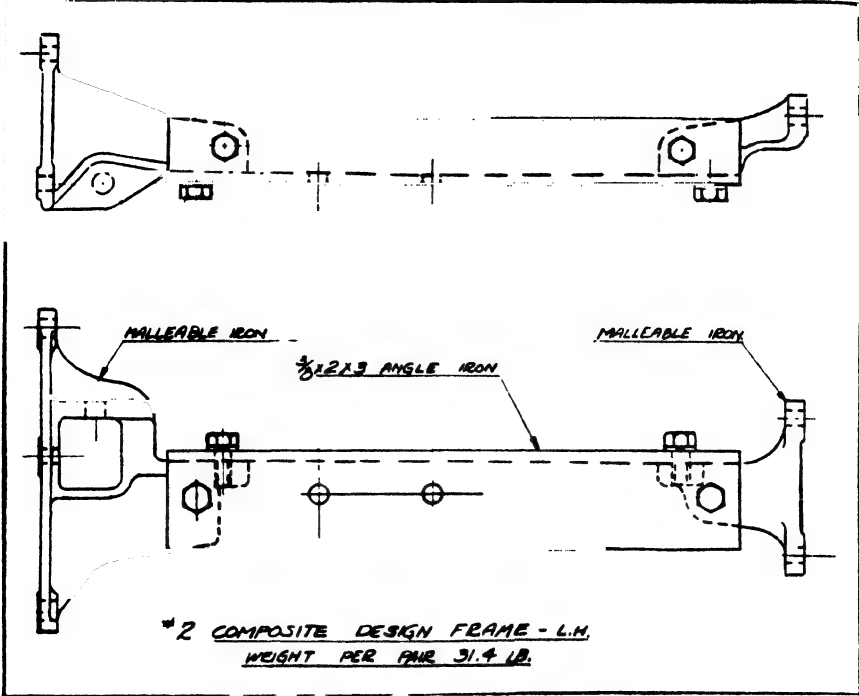



Fig. 18. Design #2, the composite frame.

A saving of $5\frac{1}{2}$-minutes is made on this tube assembly by arc welding as compared with brazing. When overhead is added this amounts to $8\frac{1}{2}$ percent of the cost of the tube assembly. The holes for plug welding are formed by two projections on the main core and therefore add no appreciable cost. Brazing, at these holes only, did not give sufficient strength.

(D.), Sheave Stud—This is 1.125-inches diameter x 5-inches long with a 1.62-inch diameter head, (See Figs. 14 and 15). This part would normally be made in an automatic screw machine. The head is a standard washer button or plug welded at the end of a pin by welding through the hole in the washer. A row of pins are set in a fixture with recesses which hold the washers concentric while welding. The pin is cyanide hardened all over after welding. Projection welding does not give enough strength in this case.

Costs—non-welded part considered 100 percent for comparison.

Automatic Screw Machine Method	Percent	Arc Welded Method	Percent
Material	44.6	Material	24.1
Labor	14.2	Labor	18.3
Heat Treat	13.0	Heat Treat	13.0
Burden	28.2	Burden	36.7
Total	100.0	Total	92.1

Saving of Steel 50 percent
Cost Reduction 8 percent

The saving in cost here is small as the welding is done by hand at

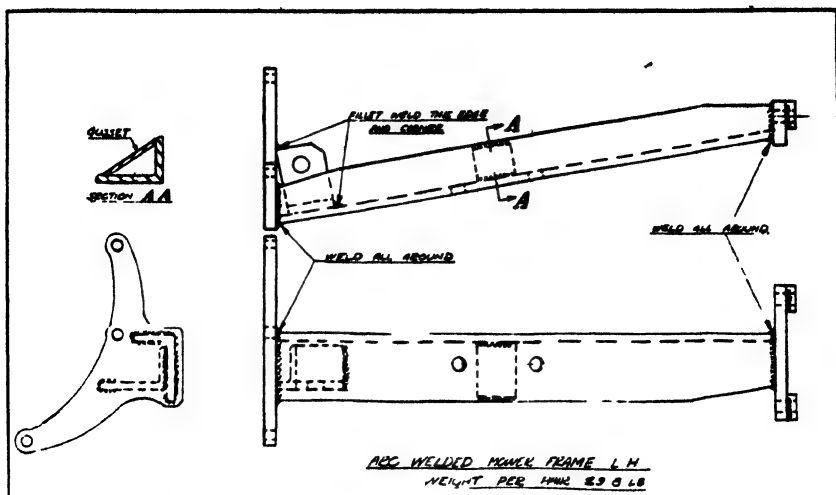



Fig. 20. Design #4, the arc welded mower frame.

present. With larger quantities a greater saving could be made by an automatic welding machine with a continuous feed. Such a machine could accommodate various diameters and lengths of pins and thus be used on long pins, shafts, screws, etc. It would be best suited for sizes upward of about 1-inch diameter as cold heading machines can produce pins in one operation in the smaller diameters because the stock is fed into the header from coils.

(E.), **Adjusting Screws**—Five of these 5/8-inch and 3/4-inch diameter screws are used per mower with lengths from 5-inches to 16-inches long. These are welded similar to the sheave studs, that is, by putting a nut with smooth hole part way over the end of the screw and plug welding the hole flush, (See Figs. 14, 15 and 16).

Welding could be eliminated on these screws by merely screwing a nut on the end of the threaded rod and let the end project through the nut as is common practice on some equipment.

This is not as satisfactory as our method because several inches of travel is necessary in most cases, and a threaded rod projecting from the nut interferes with the wrench and also is easily damaged. The welded screw turns in a cast iron plug in the end of the balance spring and the part projecting through is protected inside of the spring. The following are savings made on five of these screws used on the mower by arc welding, as compared with making them on an automatic.

Steel saved 58 percent Cost reduction 19 percent

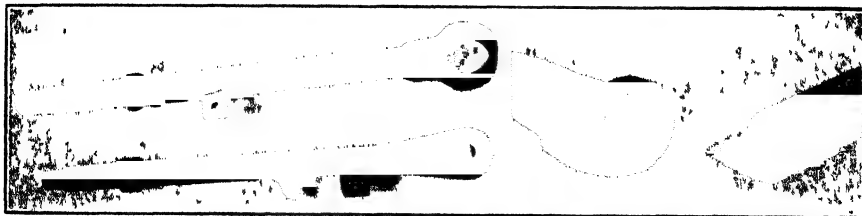



Fig. 21. (left). The drag bar first design (bottom) and second design (top). Fig. 22. (right). Typical break in drag bar due to fatigue.

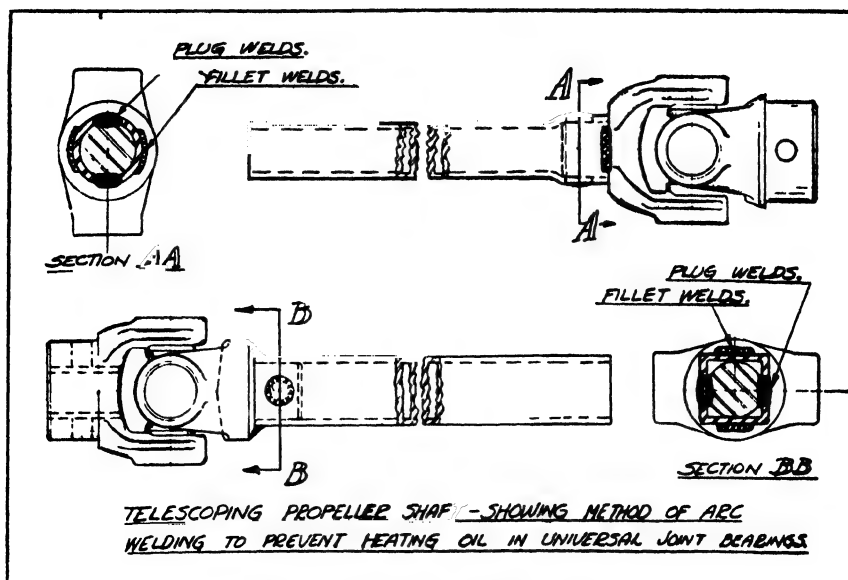



Fig. 23. Telescoping propeller shaft.

(F.), Right and Left Frame Members—These are made of 3/8- x 2- x 3-inch angle iron with steel plates fillet arc welded at each end as shown in Figs. 17 and 18. Fig. 17 shows welds in white. Before this was finally adopted, the following four designs were considered:

1. One piece malleable casting.
2. Angle iron with a malleable casting bolted on ends.
3. One piece steel castings.
4. Arc welded steel.

No. 1 was not tried as experience indicated that light section of malleable castings this length (23½-inch) usually warp too much.

No. 2 was tried and is shown in Fig. 19.

This required four different end castings and was consequently expensive as each required separate patterns, tools and machining. Also when on test it was almost impossible to keep the bolts tight, some breakage of castings also occurred.

Design No. 3 was not attempted as the cost of both the material and machining figured too high. Right and left patterns would have been required also.

The No. 4 design, (See Fig. 20), welded frames required no right or left parts, the same end plates being used for both sides of the tractor. These end plates are blanked and pierced in one operation out of 7/16-inch hot rolled plate and require no machining.

Two frames are welded in a horizontal jig at the same time. The end pieces are placed on locating pins and a hand lever brings them up against the ends of the angle irons and holds them square. A small gusset and angle bracket are also welded in place on one frame. The length of the assembly is held uniform by a stop. After tacking, the frames are removed from the jig and the remainder of the welding is done on the bench.

Comparison of No. 2, 3 and 4 design frames.
(No. 2 considered 100 percent for comparative purposes)

	Weight per pair		Cost of Pair
#2 Cast Steel Frame	34.8 lb.	= 100%	= 100%
#3 Composite Frame	31.4	= 90%	= 82%
#4 Arc Welded Steel	29.8	= 86%	= 73%

Average weight saved by welding 12 percent
Average cost reduction by welding 22½ percent

(G.), **Drag Bar**—This is a 1½-inch diameter 40 carbon alloy steel bar with four parts arc welded to it. The assembly weighs 17-pounds and is heat-treated to 388 Brinell hardness after welding.

See Fig. 21. The mower is supported on the small end of the bar and held in place in the hinge casting by a large nut. Severe bending loads occur on the bar at the section adjacent to the malleable hinge casting. Two previous designs were tried before fatigue failures at the collar were eliminated. In the first a loose collar was pinned on the shaft but the pin hole weakened the shaft causing breakage in service and also sometimes when quenching in the heat treat process.

The second design shown in upper view Fig. 21 had a narrow ring pressed on to form the shoulder and an arc weld run all around it. Breakage occurred in a few mowers however in spite of heat treating after welding. A photo of a bar which broke in service is shown in Fig. 22 and is a typical fatigue fracture. It was found that the fillet weld was undercutting the shaft slightly which allowed a concentration of high stresses at this point.

Consequently the third design shown in lower view Fig. 21 with a wide collar was tried and no more trouble occurred. The collar has a 11/16-inch diameter hole drilled through and is plug welded to the bar. In this way the weld cannot undercut and the section of greatest stress is not at the weld but at the edge of the collar. A change in design also allowed us to simplify the large end of the bar to eliminate the two reinforcement straps at the large eye for the rubber mounting bushings.

In the latest design the bushings are mounted in the drag bar bracket instead of the drag bar itself. This allows the eye to be a flat steel plate which permits ample fillet welding without any reinforcing pieces.

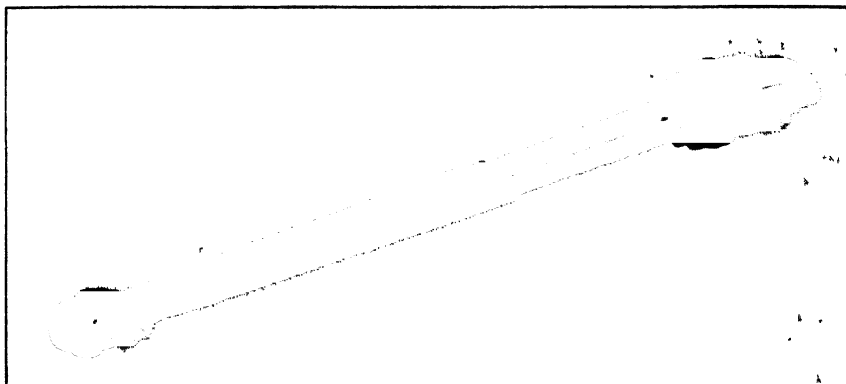



Fig. 24. Arc welded propeller shaft.

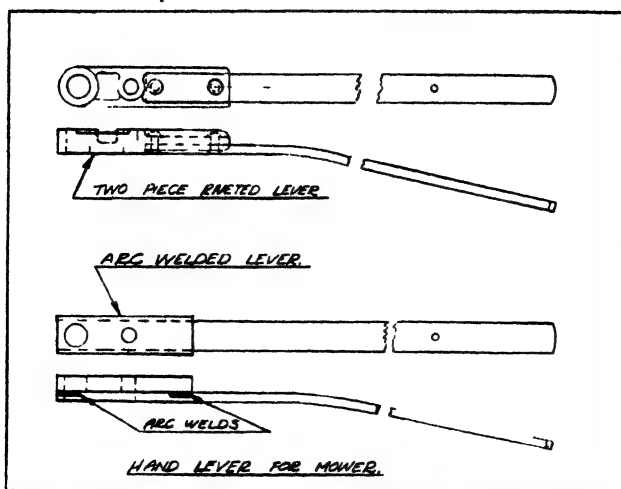



Fig. 25. Hand lever—riveted (above) and arc welded (below).

Cost of three types of drag bar based on a figure of 100 percent for #1 Bar.

1. Bar with pinned collar.. = 100%
2. With narrow collar and large eye........................ = 96%
3. Plug welded collar and plate eye........................ = 96%

Average cost reduction of #3 design 4 percent.

No saving in weight.

(H.), Propeller Shaft—The previous design was made by pinning and keying a solid shaft to one of the universal joints. The other end of the shaft was splined and mated with a splined sleeve attached to the other universal joint also by a pin and key. These shafts loosened up in service and were too expensive.

The arc welded design shown in Figs. 23 and 24 was therefore adopted.

The design of the universal joint was changed to have a 1-inch shank instead of a hole. Telescoping square tubes are pressed on these shanks and welded to the hubs of the joints. The smaller tube is expanded to 1-inch inside diameter and the larger tube has a 1-inch square hole. This permits use of exactly the same design joint for both halves of the propeller shaft.

Since the joints have already been assembled and the needle bearings oiled and sealed for the life of the joint before welding, it is necessary to avoid melting the heavy oil and cause it to run out. This is done by plug welding the two sides of the tube which are in line with the yoke arms which contain the bearings. This keeps the heat far enough away to prevent driving oil out of the bearings.

The other two sides of the tube are fillet welded to the hub also without appreciable heat reaching the bearings.

Arc welding thus permits the use of high strength cold drawn square tubing instead of the more expensive splined construction.

Comparison of the two types of shaft on a basis of 100 percent for non-welded design.

	Weight	Cost
Non-welded shaft	12 lbs. = 100%	= 100%
Arc welded shaft	10 lbs. = 83%	= 75%

Saving in weight 2 lbs. or 17 percent   Cost reduction 25 percent

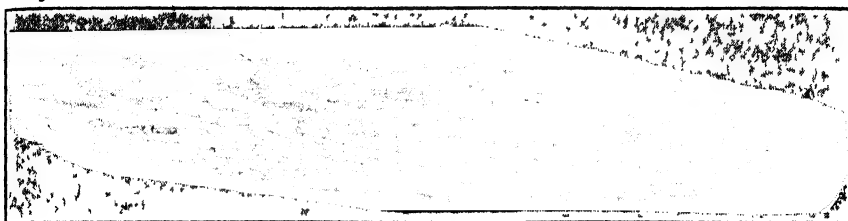



Fig. 26. Oak swathboard.

(I.), Hand Lever, (See Fig. 25)—The upper view shows previous design made of a steel bar riveted to a malleable iron casting. This has been replaced by an arc welded lever shown in the lower view. The lower part is fillet welded and acts as a stiffener also provides strength and bearing area at the pivot.

Comparison of the two types of levers based 100% for the non-welded design.

	Weight	Cost
Non-welded lever	5.1 lb. = 100%	= 100%
Arc welded lever	4.7 lbs. = 92%	= 88%

Saving in weight .3 lbs. or 8 percent

Cost reduction 12 percent

(J.), Swathboard—This is carried by the outer end of the mower bar and clears a path for the inner shoe of the mower when cutting the next swath. Fig. 26 shows an oak swathboard formerly used and Fig. 27 the present arc welded one. It so happens that each weighs exactly 7-pounds.

In cutting a heavy crop such as clover which has been partially matted down, considerable pressure is exerted on the swathboard. This resulted in a comparatively short life for the oak board at high speeds. While it has a steel reinforcement, the board sometimes splits or breaks in rough treatment. The steel board is formed of 1/16-inch steel with a flange 13/16-inch high running all around the edge. The large reinforcement is arc welded at 6 places.

It is difficult to damage or bend this steel board and consequently it fits into the high-speed mowing picture very well.

Cost comparison—Based on 100% for the wood board.

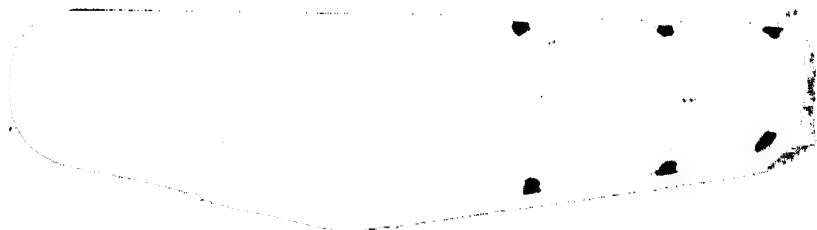



Fig. 27. Arc welded swathboard.

Summary of Savings due to Arc Welding

	Weight Saved		Reduction in Cost Percent
	Lbs	Percent	
A Crankshaft			7
B Sickle head ball	22	10	22
C Propeller shaft tube			8
D Sheave stud	1.55	50	10
E Adjusting screws	8.96	58	19
F Right and left frame	3.30	12	22
G Drag bar			4
H Propeller shaft	2.00	17	25
I Hand lever	40	8	12

Total saving per mower 16.43 lbs
Savings made per mower in percent,
Weight saved 3½%
Cost reduction 6½%

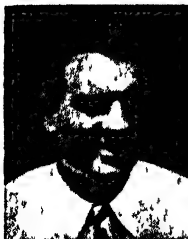
Conclusion—We are trying more applications of arc welding on this and other mowers and equipment made by our company and these will be used in production whenever experimental work proves them to have advantages

Our present yearly production of approximately 7000 mowers plus service parts results in savings of $43,995 per year including 123,000 pounds of material saved

Use of arc welding to the same extent by other makers of industrial mowers would, it is estimated, save at least $225,000 annually and release about 630,000 pounds of vital material for other uses

Chapter XXX—One-Piece Design of Farm Sprayer

By J. R. Love

Manager and Engineer, Love Tractor, Inc., Eau Claire, Michigan

J. R. Love

Subject Matter: Design, construction, advantages, and cost of an arc welded sprayer. Arc welded step platforms for tractors and a welded disc harrow are also described. The arc welded sprayer is of all-metal construction having a tank of frameless-transport-trailer construction, protected straight-in-line power take off, pump in the rear, and tank in the front to give better load distribution. The welded construction of this sprayer decreased the weight 800-pounds and decreased the cost $60 per unit. Many features of this unit would not have been possible without welding.

In writing this paper, my main objective is not to point out how any one particular item manufactured by us is produced cheaper, stronger or more beautiful or better in any other respect, by electric arc welding process. Rather, I would like to prove to you that arc welding design can be practiced in general throughout the farm machinery manufacturing industry, in particular to a great advantage, not only to the manufacturer, but to the farmer as well. To do this, I would like to give you, first, a resumé of our business.

I am the manager and chief stockholder of a small farm equipment manufacturing corporation. Because of the ever growing competition, a small company, such as ours, must build exceptionally good products to sell them in the same market with the products of national reputation, and we are obliged to cut the cost of each individual unit as we cannot look to quantity buying and mass production as a means of lowering costs.

From 1932 to 1936, we built farm tractors exclusively. These units were built up from standard automotive units. By careful selection of these units, we were able to secure a full floating truck rear axle and truck transmission which had properly balanced gear ratios and capacities to be used with the four cylinder, battery ignition and starter equipped motor. These tractors, were of course, all rubber tire equipped. The functional units of this tractor were mounted in a frame made of structural steel shapes and castings, bolted together.

However, in 1936, we lost all of our patterns (several thousands of dollars worth) when the foundry burned down. Neither we, nor the foundry had these patterns insured and consequently, they were a total loss to us.

When we started design of our 1937 tractor, we were determined to eliminate every casting that we had formally finished ourselves and thereby eliminate the need of any pattern equipment, regardless of comparative cost of the cast part and the fabricated steel part. We were influenced to eliminate patterns, not only by the chance of destruction, such as the fire we had just been the victim of, but more so because the automotive units that we

used in our tractor were continually being redesigned and consequently meant that we had to change the shape of our parts, in order to adapt them.

Such a procedure invariably meant the obsolescence of the old pattern and the making of a new one to replace it.

In this, our first experience of steel fabricated parts, we not only produced a more beautiful and more serviceable tractor, but were able to produce each unit cheaper and without the necessity of investing our much needed capital in expensive pattern equipment.

The foregoing, is of course history for which we cannot take too much credit, as it happened more as an accident than as any great thinking on my part. However, it left one indelible fact with me which has had more influence in the continued success of our business than all other facts combined. That is, no matter what the equipment may be, fabricate it from structural steel, if at all possible. It can be said, in practically every instance that whether the requirements are for a single experimental unit, or for mass production, that it is less expensive to fabricate from steel shapes, than it is to make by casting.

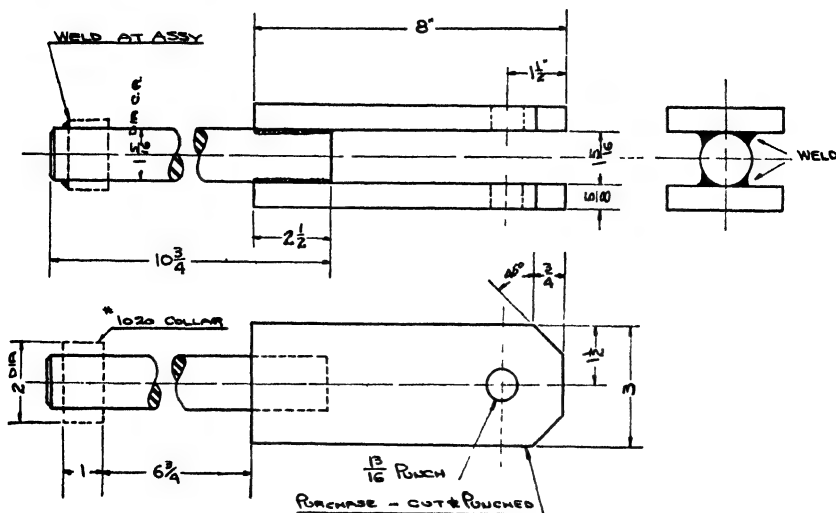



Fig. 1. Sprayer hitch.

The equipment we have available to fabricate our steel consists of the following:

Electric arc welding motor generators, shear and hole punches, drill presses, flame shape cutting machine, stationary and portable grinders, hydraulic presses and power roll.

These machines are not only less expensive in their sum total than the machines that are necessary to finish comparable cast parts, but they serve many more uses in shop maintanence and (especially since the War Emergencies) as repair and service means of keeping other equipment in use, beyond its normal life.

Our tractors, from the earliest model in 1932, were equipped with rubber tires and self starter, these tractors were and still are, in truth, of the most modern design. However, when the new Ford-Ferguson tractor was put on the market, we believed it wise not to compete with this tractor, because in

our estimation, it is the answer to the farmers' demands for a small but powerful modern tractor; at low cost; and such being the case, it would be much harder to sell our own. We, therefore, decided that we would be much better off to "hitch on to their band-wagon" and "get a free ride" by producing equipment designed especially for use with this Ford tractor. Incidentally, although the Ford tractor, in outward appearances, is based on cast design, electric arc welding is used in many places, such as the radiator to the front motor support bracket, the radiator grille, the radiator side shields, the radiator itself, the hood, etc. But probably the biggest saving they make is the least obvious—many thousands of dollars worth of castings for all parts of the tractor, from the front axle to the rear axle inclusive, are saved from the scrap heap by patch welding. Blow holes, cracks and other flaws or defects which would make the castings unfit for use either because of appearance or the fact that they would leak grease or would not have the required strength, are patch welded into usability.

The alloy used in casting these Ford tractor parts is much stronger than any previously used for similar parts. This means that these parts can be cast thinner and therefore lighter in weight without losing any strength. This saving of casting weight is of course, a direct saving. But this saving would be partially nullified if not wholly lost, because of the difficulty in casting this material and the subsequent appearance of defects as mentioned above, if it were not for the fact that a very few cents worth of electric arc welding with the proper alloy electrode repairs these castings to the proper standards of strength and appearance.

The first accessory that we built to sell with the Ford tractor, was a set of step platforms or running boards. These platforms supplied the one comfort that the Ford engineers omitted in designing the tractor. The chief purpose of these steps was to allow the tractor operator to drive the tractor from a standing position. Most tractors provide a means so the operator can stand up occasionally because the change in position relieves the strain of driving, particularly on rough ground. These step platforms also serve as an easier means of getting on and off the tractor.

The corner edges are rounded and the unit tapers from a wide width at the back edge, where the driver stands, to a narrow width on the front or leading edges. These platforms were formed from 14-gauge blue sheet steel. They were tapered narrow to the front, and held narrow enough on the overall width of the widest part so that they could be left on the tractor while cultivating corn or other row crops. In order that the outer edge of these platforms would not cut or injure row crop plants as the platform passed by them, a piece of round edge flat stock, ¼-inch thick by 1½-inch wide, was formed to the shape of the outer edge of the sheet and arc welded to it so the wide flat surface of this material came in contact with the row crop plants. This flat bar also served to give added strength to this 14-gauge platform material. A pair of these platforms were bolted to a pair of angle iron supports which were mounted transversely under the tractor transmission housing. To these angles, were welded two steel straps or lugs, which served as mounting bosses for bolting to the underside of this transmission housing.

The flat 14-gauge sheets were sheared and trimmed from templates and formed in a press break. The jigs for holding this sheet and the rolled ¼-inch by 1½-inch flat strap while the two were being welded together and the jigs for holding the support angle and the mounting bosses were made by welding structural steel shapes. Together with the template for shearing, in all, cost $86. These platforms were manufactured in lots of 100 sets and from all

appearances it looked as though it would be a very profitable improvement for the tractor. In fact, it looked so good, one of the Ford tractor distributers influenced another company to manufacture a similar product.

This company copied the shape of our platform identically and decided the product was good enough to warrant manufacturing it by the thousands, and spent over $5000 making fixtures and dies to stamp or press these out of a sheet without welding, they started a sales campaign at once.

This product was very acceptable to the farmer, but both ourselves and the other company overlooked one important fact. The most important fact, that is, that the product was not acceptable to the Ford dealer, our only suitable medium of selling or contacting the Ford tractor owner. This product was not acceptable to the dealer because invariably, when the farmer saw the platforms, he wanted them but insisted they be "thrown in" with the tractor deal, or else "the deal would be off". The dealer soon became tired of this, consequently it was very difficult to sell more than the first or second set to any dealer. Because the tractor was a new product, there was not, at that time, nor is there as yet, enough tractors out to make it profitable for the dealer to handle these as an accessory for tractors already sold. However, that day will come. In the meantime, we have been able to sell a few hundred sets, enough to pay for our inexpensive welding fixtures and advertising and give us a fair profit besides. While the "smart alecs" who copied our platform have not even begun to pay for their $5000 fixtures nor their expensive advertising. If their cost of manufacturing is any less by stamping, which I doubt, as it requires a larger size sheet and consequently more waste or scrap, they will have to make many thousands of these units before their present losses will be amortized. Long before they have broken even, we will have made a considerable profit and have ample time to investigate the marketing possibilities of these platforms, and other manufacturing methods.

After having learned this valuable lesson without loss, we decided that we would be wise to manufacture a unit that would be a source of considerable profit to the Ford tractor dealer, and a unit that would not only be acceptable to the farmer, but that could be sold to him without too much "chiseling" because of competition.

Being located in the center of the richest fruit farming area in the United States, we are, of course, very familiar with the problems encountered by these farmers and their desires for improved equipment. The most important piece of equipment, other than their farm tractor, is the power sprayer; and in particular the tractor power-take-off, power sprayer, that is, a sprayer which gets the necessary power to drive the spray pump from the tractor motor by taking power off a shaft extending from the rear of the tractor by means of a telescoping tube and shaft and universal joints, connecting from the power-take-off shaft on the rear of the tractor to the shaft to be driven on the sprayer. The universal joints provide a flexible coupling means between the two units.

However, the power-take-off sprayers built by all companies date back to the original conception of a sprayer when the farming was done by horses. The horse-drawn sprayers, naturally had to have their own motor. The conventional design then used by all companies was to set the motor on the front of the sprayer to drive the pump by means of reduced speed by use of a chain and sprocket reduction. On the back of the pump was another sprocket drive which drove the agitator shaft after a further reduction in speed. This agitator shaft extended through the 100- to 300-gallon wood tank which held the spray liquid and agitated this spray liquid by means of paddles attached to

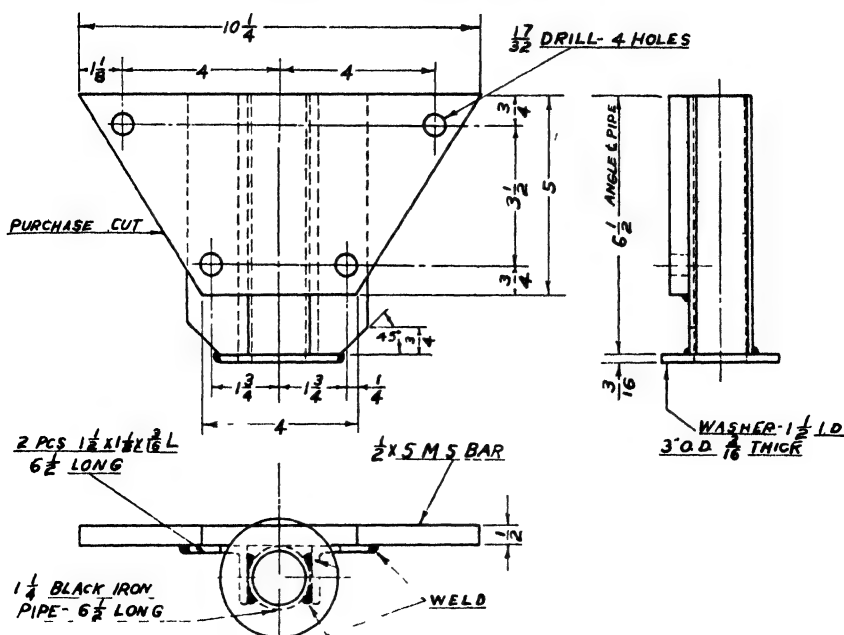



Fig. 2. Hitch pivot bracket.

the shaft. In this horse drawn version, there was of course, a front axle and a rear axle. Some units were made on skids and set on wagons, others were built using a channel iron frame to which were bolted the two axles, the front axle being on the very front of the rig and the rear axle being approximately under the center of the tank. When these companies redesigned their sprayers for use with tractor power-take-off's they simply eliminated the motor, and in its place put a jack shaft with the sprocket to drive the pump. The tractor power-take-off universal drive shaft was connected to this jack shaft. The front wheel and trucks of the sprayer were eliminated and a hitch made to connect to the tractor draw bar. The rear axle of the sprayer was left in essentially the same place, that is, under the center of the tank. The farmers have found the following faults with this sprayer:

Because of the weight of the pump and drive mechanism and the frame, the front of the sprayer weighed about 800-pounds and consequently could not be lifted to mount it to the tractor nor could the sprayer be moved about for storage in his tool shed. Probably the biggest objection was the always present threat of serious injury because the power-take-off universal drive shaft extended from the rear of the tractor over the sprayer tongue, and the tractor operator had to work very close to this shaft, both while operating the unit and while servicing the pump. Most companies today provide a shield to guard against injury from this revolving shaft. However, these shields are separate loose pieces and are sooner or later discarded by the operator because of the nuisance of putting them on, or because they are misplaced or even bent from handling. The open chain and sprocket drives on this pump had to work under dusty conditions and wore fast, requiring constant adjustment and frequent replacement.

The wood tank in these units dried out and shrunk during the unused

periods and had to be soaked up for several hours or sometimes several days before they stopped leaking.

Because the axle was located under the center of the tank, the spray liquid would run to the back of the tank when the tractor and sprayer were going up a steep hill. This naturally concentrated the spray material behind the sprayer axle and had a tendency to lift the front of the sprayer. This took the weight off the sprayer tongue which in turn reduced the weight on the wheels of the tractor and caused the tractor to lose pulling traction when it was climbing a hill and needed it most.

In considering the possibilities adherent to the manufacture of farm power sprayers, we found that there were about one-half dozen companies producing 5000 sprayers suitable for general farming operations. There were a few other companies listed as power sprayer manufacturers who built an additional 4000 units per year. But these were, in reality, "glorified barrel pump sprayers." In further breaking down of the data on sprayers, we found that about one half of these units were tractor drawn power-take-off driven sprayers. This meant that each of the major manufacturing companies were building 300 to 500 of this type of sprayers per year.

This also meant that the demand for sprayers did not warrant mass production and therefore would not interest any larger company. In fact, because of the number of models produced by these companies, they could not approach any semblance of volume production on any type sprayer. This meant that we would be able to produce sprayers, at least on an equal footing with the other companies. And all these companies were building units exactly alike, differing only in the actual details of construction. We therefore felt confident that we could greatly improve the sprayer, and at the same time, price it so that the Ford tractor dealer would be interested in handling it.

In February, 1940, we started to lay out the experimental model. On March 20, 1940, we finished the first sprayer and immediately put it to actual field tests on a neighboring farm. We are proud to say, this sprayer has operated continously since that time, and we have not found it necessary to make any change in design.

We immediately, thereafter, started production on these sprayers, building them to the proper height and balance so that they made a perfect combination with the Ford tractor, and as was our belief in the beginning, they were enthusiastically accepted by the dealers, because they were a good source of extra profit for him, and were equal in quality and appearance to the Ford tractor. The dealers found them very easy to sell as it was a simple matter to point out their superiority over the conventional sprayer.

We accomplished all the improvements demanded by the farmers and were able to build a lighter, cheaper and yet stronger and more durable unit than any on the market at that time.

The conventional sprayer consists of the several individual units assembled together, namely:

An axle and wheels, frame, tank, pump, pump sub-frame, the power-take-off drive mechanism and the operater platform and guard rails. These separate items were bolted together to produce the finished product. Both the wood and steel tank units illustrate that the old line companies had retained the same principle of design in their most modern units.

By using an all steel welded construction, we are able to eliminate the frame and axle by letting the steel tank serve for all three. The platform, guard rails and pump sub-frame are combined in one frame unit. Stub

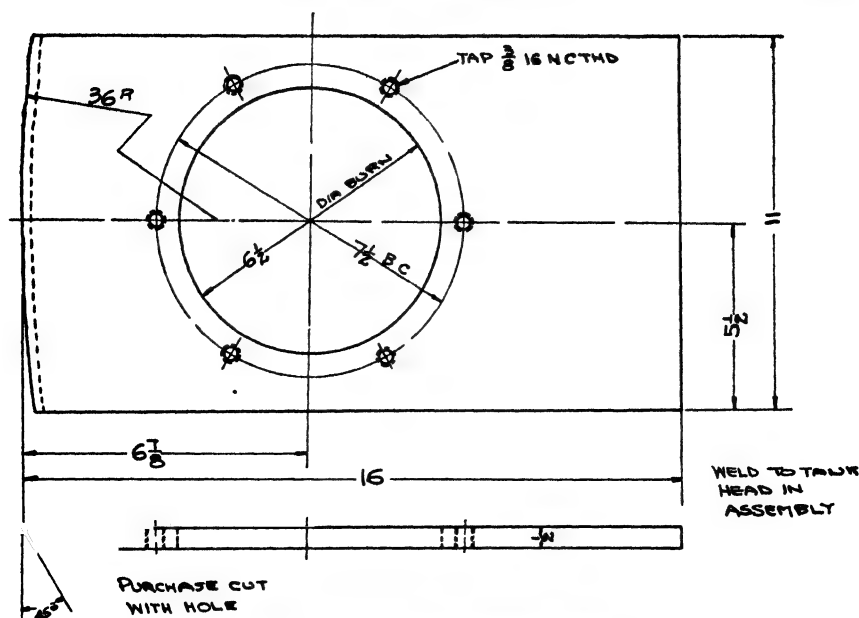



Fig. 3. Tank agitator bearing plate.

wheel spindles are bolted to the side of the tank and sub-frame where they are bolted together, using the same bolts.

Each of the improvements asked for by the fruit growers has been accomplished. First, the power-take-off which is above the tongue and hitch on the conventional model, is covered or protected by merely reversing its position. That is, it is put underneath the sprayer tongue where the operator cannot possibly fall into it, or otherwise come in contact with it. It is possible to do this without lowering the shaft too low to the ground because we weld the tapered nose piece (which forms the front part of our sprayer frame) to the top of the sides of the spray tank, whereas in the conventional sprayer the frames are built from structural iron (usually channel) and the tank sets on top of this frame, so that the whole frame is very low to the ground, and the power-take-off shaft of necessity, has to come out above the front or hitch part of the frame.

We use a special design of pump which contains its own reduction unit of enclosed gears running in oil. This pump mounts on the rear of the sprayer behind the tank. The power-take-off drive shaft passes through the tank with paddle wheels attached, thereby serving as an agitator shaft as well. The stub spindles are bolted at the rear of the tank, and by putting the pump at the proper distance behind the tank, the combined weight of this pump and platform guard rail sub-frame assembly, balances the weight of the empty spray tank and nose hitching piece, (See Figs. 1 and 2), so that the front of the sprayer can be picked up with one hand and rolled about on a smooth floor as easy as a wheelbarrow.

Because the tank is ahead of the sprayer axle, the weight of the spray liquid is carried between the sprayer axle and the rear axle of the tractor. Approximately 40 per cent of this liquid load being carried on the tractor rear axle and the remaining 60 per cent on the sprayer axle. Whereas the

total load of the spray solution is carried on the axle of a conventional sprayer, in as much as it is under the center of the tank.

When our unit is going up a steep hill the weight of the liquid in the spray tank shifts with the level of the liquid, as it does in the conventional units, putting most of the spray solution in the rear half of the tank. However, because our tank is completely ahead of the sprayer axle, the weight of the spray solution can never be concentrated behind the sprayer axle. Actually, the tank hangs between the sprayer axle and the tractor rear axle. Therefore, the weight of the spray solution is always divided between these two axles so that the tractor always gets added pulling traction from the weight of the liquid in our unit, regardless of how steep the hill may be.

The design of our sprayer is based entirely on fabricated and arc welded steel construction. Our sprayer weighs 1500-pounds as compared to 2400-pounds for a conventional sprayer of the same capacity. The spray pumps in both units are of comparable design and weigh about 400-pounds each. This means that our unit, complete, less the pump weighs 1100-pounds as against 2000-pounds for the conventional unit. This saving in weight could not have been accomplished without the use of electric arc welding.

Even at this particular time, when the saving of steel is most important, our sprayer still compares favorably, in as much as the wood tank of a 300-gallon conventional sprayer weighs about 300-pounds. This means that the frame, axle, wheels, pump sub-frame, platform and guard rails, less the pump and wood tank, weigh 1700-pounds, as against 1100-pounds for our complete sprayer less the pump. In both cases all of this weight is steel except for the sprayer hose, gun and tires. These accessories total about 100-pounds leaving a net of 1600-pounds of steel for the competitive unit less the tank, as against a net for our unit less the same accessories, but complete with tank, of 1000-pounds of steel.

This means that the steel in the competitive unit weighs 60 per cent

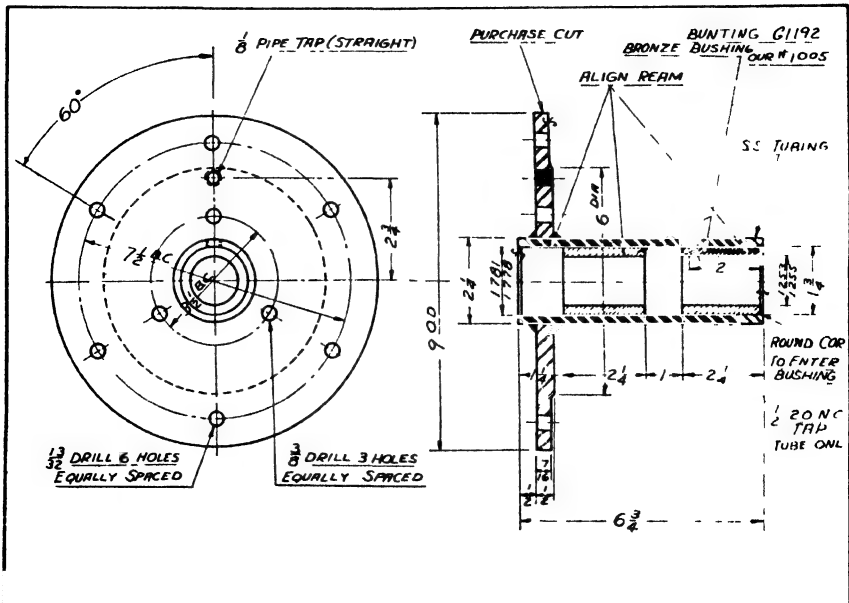



Fig. 4. Agitator bearing.

more than our unit complete with the tank, or a direct saving of 600-pounds of steel. The net cost of this steel, whether bought by mill or warehouse shipment, when freight and handling charges are considered, and the cost of procurement, would not be less than 3½-cents per pound or $21. This, plus $40 to $45, the cost of a 300-gallon wood tank, not assembled, makes an obvious saving of $61 or not less than $60 but as much as $65 per unit.

The construction of our sprayer is based entirely on what we term, "our finished tank assembly". The actual spray tank is 40-inches wide by 40-inches high by 48-inches long. The shell or body of the tank is made of a sheet of 12-gauge hot-rolled-pickled-and-oiled steel 48-inches wide by 144-inches long. The tank ends are made of 3/16-inch thick hot-rolled-pickled-and-oiled steel 40-inches by 40-inches, the bottom edge is cut on 36-inch radius to form a round bottom on the tank. All four corners are trimmed on 9-inch radius, the bottom blending to the 36-inch radius. The 12-gauge sheet is rolled to conform to the shape of these tank heads with the seam on the top center of the tank welded inside and outside. The tank heads are set back in ¾-inch from the edge of the 12-gauge shell. A continuous weld is run on both sides of the tank heads, thereby closing all seams so that corrosion or rust cannot have any hidden place in which to start.

The tank shell and heads are completely tack welded together first, as is common practice. After the heads are welded in, a 16¼-inch round hole is flame cut in the center of the top of the tank. A rim or hoop made of ¼-inch by 1¾-inch flat steel is rolled, the easy way, to an outside diameter of 17¾-inch and butt welded. This ring is welded on the top of the tank, around the hole to form a rim for the tank cover. This ring is welded to the tank shell inside and outside, and of course serves as a re-enforcing member for the top of the tank. The cover is made from 12-gauge with a one-inch lip formed so that it will fit freely over the above-mentioned rim.

The hinge is made by welding a piece of ⅜-inch pipe cut 2-inches long to a piece of ¼-inch x 2-inches flat stock which in turn is welded to the top of this cover. A 7/16-inch diameter bolt fits through this piece of ⅜-inch pipe cover. A 7/16-inch diameter bolt fits through this piece of ⅜-inch pipe to form the pivoting member for the hinge. Two pieces of ¼-inch x 1¼-inch flat stock are cut the proper length and punched 15/32-inch diameter to fit over this 7/16-inch pivot bolt. These ¼-inch x 1¼-inch flat pieces are butt welded to the top of the tank far enough apart so the ¼-inch x 2-inch flat stock with the pipe welded on, will fit freely between them forming the stationary member of the hinge.

This earlier construction shown was necessary because we were purchasing the cover assembly complete from an outside source. The stationary member of this hinge was formed in a U shape rather than by two straight upright straps butt welded to the top of the tank. However, after the 1940 and 1941 seasons, we began to have complaints of too much rust or corrosion around these hinges. The most dangerous place being where the stationary or U shape part of the hinge was fastened to the tank. This was merely tack welded where the bottom or flat part of the U set on the top of the tank. This corrosion was being caused by the corrosive spray solution seeping into the crack between the hinge and the cover or the hinge and the top of the tank. We changed our source of supply and bought the cover only with the rolled flange from a tank-head company and welded the hinge on in the manner described. This of course, completely sealed the joints between the tank and hinge and cover so that no spray material could seep in to start corrosion. Welding, in this case, most obviously meant greater

serviceability or durability. We also are making this assembly for 46-cents per each less than we purchased them for in 1940 and 1941. We cannot, of course know for certain that this saving is traceable to arc welding, but as far as we are concerned, the use of arc welding was the means of making this saving. It is obvious, in this instance, that the welding saved the punching or drilling of 12 holes, 6 rivets and the time necessary for riveting and bending of the stationary hinge piece plus the saving of a 2-inch length of 1/4-inch x 1 1/4-inch flat iron.

For a quick comparison of this earlier method to the welded construction, we believe that the welding time and material would compare very favorably with the riveting time and the 6 rivets. The saving being in the forming of the 12 holes and the small piece of flat steel. However, in this instance, the most important consideration was not the cost but rather greater serviceability.

A 3-inch pipe flange is welded to the center of the bottom of the tank. After welding it on the tank around the outside, the tank shell is burned out of the inside of this flange to form the drain hole. This flange is also welded on the inside to close the joint between the tank shell and the flange in order to prevent corrosion.

On the front end of the tank is welded the nose piece. This is formed by bending a piece of 3/16-inch by 12-inches wide by 80-inches long mild steel to form a V. This is bent in a die to form a 3-inch radius at the front or V end. The back edges are bent for a distance of 5-inches back from the end, so they will lay flat against the sides of the tank and are welded all around. This weld actually supports 40 per cent of the weight of the spray solution. This nose piece has ample vertical strength to support this weight plus any shock loads. One-inch from the bottom of this nose piece, a 12-gauge sheet, the shape of the opening formed by the V and the tank head, is welded solidly to it so that it cannot buckle sideways. It also serves to re-enforce the tank head so that it will not dish or vibrate. At the same time, it forms a bottom on the nose piece, making a very convenient carry all compartment for additional spray guns or hose or other tools and accessories. On the front and underneath side of this bottom is bolted the sprayer hitch. The part of the tractor hitch that fits over the tractor drawbar is made by welding two pieces of 5/8-inch by 3-inch flat by 8-inches long, on the opposite sides of a 1 5/16-inch round bar 11-inches long, overlapping the round bar 2 1/2-inches of the lengthwise dimension. This 1 5/16-inch round pivots in a piece of 1 1/4-inch pipe which is welded to two angles which in turn are welded to a 1/2-inch thick flat plate. The flat plate being the member which bolts to the bottom of the sprayer nose.

In the bottom of this front nose piece is welded a 1 1/4-inch pipe coupling, on each side of this coupling are welded re-enforcing triangular shaped gussets which are cut from 10- or 12-gauge scrap sheet. These gussets re-enforce the bottom sheet around the pipe coupling. In this pipe coupling is screwed a piece of 1 1/4-inch pipe, 11-inches long, having a hole drilled near the bottom end. A piece of 1-inch pipe 24-inches long, fits freely inside of this pipe. These pipes are used as a telescoping standard to hold the front of the sprayer up when not in use. A 3/8-inch cotter pin that has been sprung apart just enough to make it have a little tension, fits through the hole in the bottom of the 1 1/4-inch pipe and corresponding holes in the 1-inch by 24-inch pipe leg. When the sprayer is being used, the leg is pushed up into the pipe, out of the way and held up by the use of this cotter pin in the same manner as when using the leg for a stand.

Across the back head of the spray tank, is welded a piece of 2-inch by 2-inch by 1/4-inch angle, this is at about the same height as the bottom of the nose piece on the front head of the sprayer. This angle serves as a re-enforcing member, to stiffen the head. A 3/4-inch pipe flange is welded to the upper center of this head and a 1 1/4-inch pipe coupling is welded in the lower left hand corner.

The flange and coupling are welded inside and outside of the tank, so that, here again, we seal the connection against corrosion by closing the joint with welding. The upper connection is used for the overflow or pressure discharge return from the pump to the tank. The 1 1/4-inch coupling is used for a suction line to the pump. Inside the tank a 1 1/4-inch pipe nipple is screwed into this coupling with a 90 degree elbow attached, being the proper length, so that another shorter 1 1/4-inch nipple which is screwed into this elbow sets directly into the sump, in the bottom of the tank, formed by the 3-inch welding flange.

The next operation consists of mounting the tank agitator bearing plates to the ends of the tank, (See Figs. 3 and 4). One end of this plate is burned on 36-inch radius. This edge being trimmed on a 45-degree bevel. This radius is made to conform to the tank bottom radius. The 6 1/2-inch diameter burned hole in this plate corresponds to the 6 1/2-inch diameter hole burned in the lower center of the heads of the tank. In comparing these dimensions it will be apparent that these plates set against the tank heads so that the bottom burned radius rests on the 3/4-inch protruding lip of the tank shell. The reason for the 45-degree bevel edge on this plate, is so that the plate can fit up tightly to the tank head and the edge of the tank shell. The bevel part clearing the fillet weld between the tank head and shell. The top of this plate just clears the re-enforcing angle welded across the back head; and the bottom of the nose section on the front head. The 6 1/2-inch diameter burned hole is of course, made to correspond with the holes in the tank heads. As the title of these plates would indicate, they are used to mount the bearing housings for the agitators or drive shaft. Before describing the method of mounting these plates, I believe it best to explain the fabrication of the agitator bearings. In this way I can keep the manufacturing operations on the tank, in their proper sequence.

These bearing housings are made by burning a disc of 9-inch outside diameter by 2 1/4-inch inside diameter out of 1/2-inch steel plate. In this is welded a piece of cold finished seamless tubing 6 3/4 inches long by 2 1/4-inch outside diameter by 1 3/4-inch inside diameter. This tubing is machined true on both ends before welding. By so doing, it is a simple matter to hold the disc and tube at right angles to one another while welding, by merely clamping the disc securely to a flat plate with 1/2-inch spacers between and holding the tube down tight on its machined end surface against the same flat plate. (We do not have a special jig for doing this, but use a table which is 36 inches square by 1 1/2-inch thick. This table is full of tapped holes for various hold down bolts and is used for holding drop center rims and discs when building up wheels or whenever it is necessary to hold two or more pieces in true relation to one another. To hold this agitator bearing, we use a bolt in the center of this plate with a heavy washer to clamp the tube down. The disc is held down by merely laying a similar but heavier disc, built up to 2 inches thick, on top of it. This hold down disc has the hole burned out in the center, sufficiently large to allow clearance for arc welding. After running this inside bead the bearing is turned over and the outside bead is welded on).

Two brass bushings are then pressed into the tube and align reamed to finished size for the 1¼-inch drive shaft.

A slight amount of warpage is encountered in the tube when welded into the disc, for this reason, the brass bushings are pushed in from the far end so they do not have to be pushed through the part where the welding took place. After reaming the bushings, the bearing is returned to the lathe where this outer end is bored out about 1/32-inch large diameter in to the face of the bronze bushing. This trues the surface up where it was welded so that the packing and packing nut pilot is true on the shaft. The bearing is then put on an arbor and the inner face is machined true to about a 6-inch diameter or enough less than 6½-inches so that we are certain to have a true surface where this bearing bolts to the bearing plate. This bearing is jig drilled then bolted to the bearing plate without a gasket.

We are now ready to weld the bearing plates to the tank heads. Because of the length of the bearing and the close fit of the bushings to the shaft, it is necessary to have the bearings at each end of the tank in perfect alignment. A 1¼-inch shaft is put through the tank, and the bearings with the plates bolted on are shoved onto this shaft, and up to the respective tank heads, with this close fitting shaft in the bearings, they are of course, in perfect alignment. But we do not weld this bearing plate directly to the tank head. Because the tank head is distorted to some extent when it is welded into the shell and consequently, would leave some rather wide gaps which would be difficult to weld. But more important, is the fact that in welding onto this 3/16-inch tank head, we find there is additional distortion, due to the length of the weld and the heat generated. Therefore, it is practically impossible to weld this bearing plate to the head in the true relation necessary. This difficulty is very simply overcome by using bars of ⅜-inch square stock 16-inches long, to lay against each side of the bearing plate. These bars are bent to whatever shape necessary to conform to the tank head, thereby closing the gap between the two. At the same time, they are kept straight about their other axis, so that they lay up tight against the side of the bearing plate. By holding these bars tight against the tank head and the bearing plate and welding the bar to the tank head, the distortion due to heat takes place between the head and square bars without disturbing the bearing plate. After the bars are welded to the tank head on each side of the bearing plate and allowed to cool, the bearing plate is tack welded for a short distance to one of the bars. The welder immediately tack welds directly opposite this first weld to the other bar. There is sufficient metal in the bars to absorb the heat so that no further distortion takes place in the tank head. But there is a small amount of distortion caused by the shrinking of the weld when cooling. The welder, after tacking the plate to both bars, on both ends of the tank, pulls the 1¼-inch shaft out of the farther bearing . By looking in the tank he can determine if the shaft is directly in line with the bearing in the other end of the tank. If it is not, he pulls the shaft over in line by making additional tack welds on the bearing plate. For example: if the shaft is low and to his right as it hangs out of the bearing on the inside opposite end of the tank, he welds to the lower right side on the plate. As the weld cools and shrinks, it pulls the plate in and toward this weld. This raises the end of the shaft toward the center of the hole. With but very little practice, any welder familiar with the characteristics of welding steel, can aim this shaft, dead center. The bearings are removed after these plates have been welded all around, that is, the sides to the ⅜-inch square bars, and the bottom edge to the bottom of the shell and the top edge to the underneath side of the

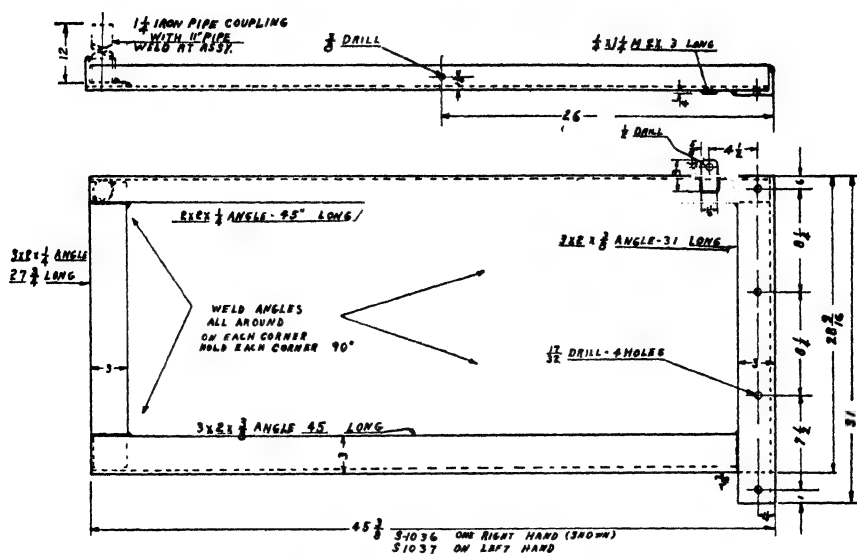



Fig. 5. Sprayer sub-frame.

angle on the rear of the tank or the bottom of the carry all compartment on the front of the tank. The tank heads are welded to the bearing plate completely around the circumference of the 6½-inch diameter holes, thereby sealing these last seams through which spray material might seep and cause corrosion.

This completes the welding operations on this tank with the exception of the drilled ½-inch by 8-inch by 26-inch side plates which are mounted to the rear of the tank.

In reviewing the procedure so far, you will note that every seam, inside and outside in this tank is completely sealed by welding and there are not braces or plates welded to the inside of the tank, nor are there any bolts put through the tank. The inside of our tank is, in fact, as smooth as a glass bottle. Therefore, when thoroughly cleaned and painted with an acid resisting paint, this tank is truly a lifetime tank, whereas the other sprayer manufacturers making steel tanks put braces and bolts through them. This does not sound like a very serious fault, but we have found that invariably serious corrosion starts wherever there are two joining surfaces of metal exposed to the spray solution. After studying this corrosion in other sprayers, it is my belief that this is not caused by corrosive action of the liquid, but rather by electrolytic action between these two pieces of metal being submerged in the spray chemicals. This does not seem too far fetched when you consider one spray solution used is blue vitriol or copper sulphate, the same chemical used in the galvanic cell, the original battery.

In this instance, welding and welding alone is the only sure method of permanently sealing the adjoining steel surfaces against this corrosive action, whether it be caused by electrolysis or merely by corrosive action of the spray solutions. This means that the normal life of the spray tank can be at least tripled, and if repainted every third or fourth year the life of the sprayer can be prolonged indefinitely. This repainting protects against rust on the body of the shell, which never takes place until the paint is knocked

off and then does not take the rapid action found in the adjoining surfaces of competitive sprayers. In one competitive make of sprayer, I have seen corrosion so severe between a brace angle tack welded on the inside of the tank head that the rust had formed and was continuing to form so thick that it was actually bulging the angle and tank head between welds. This company could have prevented this by completely welding, and thereby sealing the joints.

The next step in completing the fabrication of the sprayer is the making of the sub-frame, (See Fig. 5). These angles are cut to length and the 3-inch by 2-inch by 31-inches front upright is drilled as shown. This drilling matches the drilling on the tank side plates as these frames bolt to the inside of these plates. The proper outside end edges of the other angles are ground so that they will clear the fillet radius of the angle to which they are welded. This permits the butting together of all surfaces of the angles in order that they may be securely welded all around. These angles are welded in a jig frame which is similar in appearance to the frame itself, having locating stops and clamps to hold the angles square and otherwise in the proper relationship while being welded. After the frame is removed from the jig a 1¼-inch pipe coupling is welded in the upper rear corner of both the right and left assemblies. This serves as a mounting bracket into which are screwed the 1¼-inch by 11-inch pipe which serves as the rear part of the guard rails. The frame itself serves as the sides of these guard rails and the pump cover serves as the front part of this guard rail. The ¼-inch by 1¼-inch by 3-inch flat mild steel strap shown welded to the top side of these frames serves as the stationary members of the pump cover hinge.

The pump cover, (See Fig. 6), is formed from a sheet of 10-gauge and lays on top of these sub-frames. A 1-inch lip is bent down on the back edge and up on the front edge of this cover to stiffen it. A ½-inch standard threaded hexagon nut is welded into the front corners of this upward bent lip to serve as the other part of the hinge. A ½-inch bolt is passed through the strap on the sub-frame and screwed into this nut.

In welding the side plates to the tank, they are first bolted to a pair of sub-frames. A 1¼-inch shaft is put through the tank bearings and extends out the rear of the tank for a distance equal to the length of the sub-frames. An angle iron, long enough to extend out 5-inches beyond each side of the tank has a boss welded to its center. This boss is drilled 1¼-inch diameter exactly 2 7/16-inch from the top of the angle to the center of the hole. This boss is slipped over the 1¼-inch shaft up to the rear of the tank. The sub-frames with the side plates bolted to them are rested on this angle. This locates these frames and plates accurately so that the bottom of the sub-frames are exactly 2 7/16-inch below the center of the agitator shaft. By measuring down from the top of the tank to the top of each sub-frame they are put into position so that they are not only the right distance below the agitator shaft, but are also parallel with the top of the tank sideways. The rear part of each sub-frame is then raised or lowered so that these sub-frames are parallel with this long 1¼-inch shaft. This locates the frames accurately in all directions and the side plates are pulled against the tank by using long clamps that catch both plates at once. These plates are then securely welded all around. This completes the tank assembly and all the welding on the tank. On the rear bottom side of this sub-frame, is welded a 12-gauge steel platform. This platform has 1½-inch lips bent down on both the front and back edges, being 16-inches wide. This welded platform serves as a channel and stiffening member to hold the rear of the sub-frame in place. An 8-inch

by $38\frac{1}{2}$-inch long structural channel iron serves for the pump base or sub-frame. It is bolted to the bottom side of the spray pump with the wide flat side of the channel up. This channel is clamped to the underneath side of the sub-frames, and moved sideways so that the pump lines up properly with the agitator or drive shaft. It is then securely welded to each sub-frame.

The wheel spindles, (See Fig. 7), are purchased from a company making heavy duty truck front wheel spindles. This not only saves the cost of a forging die, but we are able to purchase this production spindle completely finished much cheaper that we could forge and finish them ourselves. The inner or king pin end of this spindle is cut off with an acetylene torch so that the inside of the inside end is flat and can be welded to a $\frac{1}{2}$-inch thick steel plate. This plate is 8-inches wide by 10-inches long and has four holes drilled in it to correspond with the four lower holes in the tank side plates. These stub spindles are clamped in a fixture together with the $\frac{1}{2}$-inch thick spindle plates so that the spindle is held square with the plate while they are being welded together.

These wheel spindles and plate assemblies are then bolted to the tank side plates. The two rear bolts for these spindles pass through the sprayer sub-frame, the tank side plates, and the spindle plate. The lower front bolt bolts through the tank side plate and the spindle plate. The upper front bolt screws into a tapped hole in the tank side plate. This is done so that it is not necessary to put this bolt through the spray tank itself. These wheel spindles, mounting to the tank side plates as they do, at the rear of the tank,

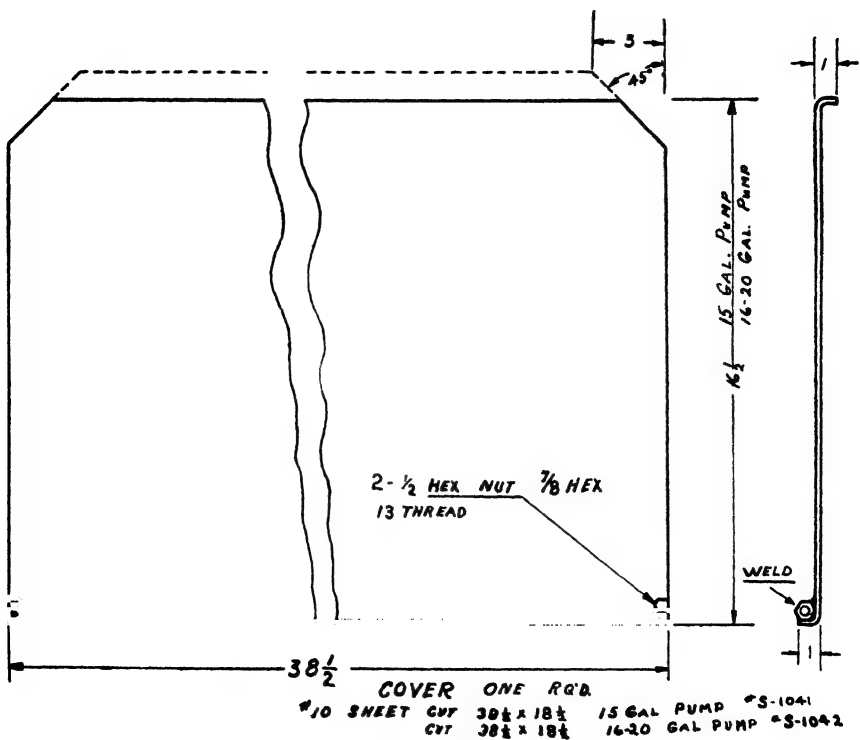



Fig. 8. Cover.

get the full strength of the cross section of the tank head and the sub-frame which is made of heavy angle iron and braced with the pump and platform channels at the bottom, forming a very strong, yet neat and simple unit.

Summary—In comparing the details of construction of our "all steel, all welded" sprayer with the pieced-together construction of others, it is apparent that our construction is superior in every way. First, it is streamlined and more attractive because of the elimination of structural frame and axle and hold down bolts and tank braces found on the conventional unit. Second, there is a remarkable cost per each saving as pointed out in the case of the total weight of steel saved and also the saving in manufacturing details, such as the tank cover. Third, we have made a much more durable or longer-lasting unit because of the protection against corrosion as mentioned. Also the strength of each part by welding into one integral unit. Fourth, the sprayer is made more serviceable because it can be handled very easily by one man, when empty he can hitch it or unhitch it from the tractor because the weight is balanced on the sprayer axle or he can push it into a corner of his tool shed for storage, where it will be out of the way. Whereas the conventional sprayer required a jack to lift the front of it because of its unbalanced design and had to be parked in the middle of the tool storage space where the tractor could be backed up and hitched to it.

Our unit is also more serviceable because of the fact that a part of the spray solution load is carried by the rear axle of the tractor. This means the sprayer load is lighter and therefore the sprayer pulls easier and this weight which is transferred to and carried by the tractor rear axle, increases the pulling traction of the tractor. This same transfer of weight is very advantageous in pulling up steep hills. In reviewing the construction of our sprayer it might be agreed that we have carried welded design to an extreme and thereby made it difficult to install service parts, or to make slight changes in specifications to meet special operating conditions. However, when the facts are fully considered it will be found that by welding, we have eliminated the necessity for replacement and where items are subject to wear, such as the agitator bearing, they are bolted on. Another example of this is the spindle plate assemblies which are bolted to the sprayer tank and sub-frame assembly. Any spindle or axle is subject to wear where the wheel bearings are mounted if not properly greased and serviced. If this happens on our sprayer either one or both spindle plate assemblies can be purchased for much less than the heavier, more complicated axle found on the conventional sprayer. In the case of the sprayer cover and hinge assembly, the 46 cents per each saved by welding rather than riveting is sufficient to warrant our selling the cover and hinge assembly as a unit, rather than as separate pieces as they could be when a riveted construction was used. Because of the change to the welded hinge we have eliminated the possibility of corrosion between the hinge connections to the tank and the cover. In eliminating this chance of corrosion, we have practically eliminated the necessity of ever replacing this cover. In so far as the changes in design for special requirements are concerned we make the tank in the following sizes: 200-, 250-, 300- and 400-gallons.

These tanks are all made the same width and have the same tank side plates welded to them. These plates are located in the same place using the same locating jig as explained in the manufacturing procedure. This means that the sub-frame mounting dimensions are exactly the same. This sub-frame is made to support three sizes of pumps. These three sizes covering the requirements of all types of spraying and all capacities within the scope of the

Ford tractor. Because the mounting dimensions are the same for all sub-frames this means that any sub-frame or pump size can be assembled to any tank size, all being formed using the same set of welding jigs. We also build this sprayer equipping it with a motor for motor drive for use where power-take-off equipment is not practical. This enables the Ford tractor dealer to have a full line of sprayer equipment, and thereby take advantage of all possible sales. These motor driven sprayers are made by merely extending the sub-frame further back giving enough room for the motor to set behind the pump. By crowding the pump and motor as far forward as possible, and by mounting the spindle plates so that the spindles are offset to the rear of the unit we still maintain our balanced weight design. This motorized sub-frame also fits all sizes of tanks.

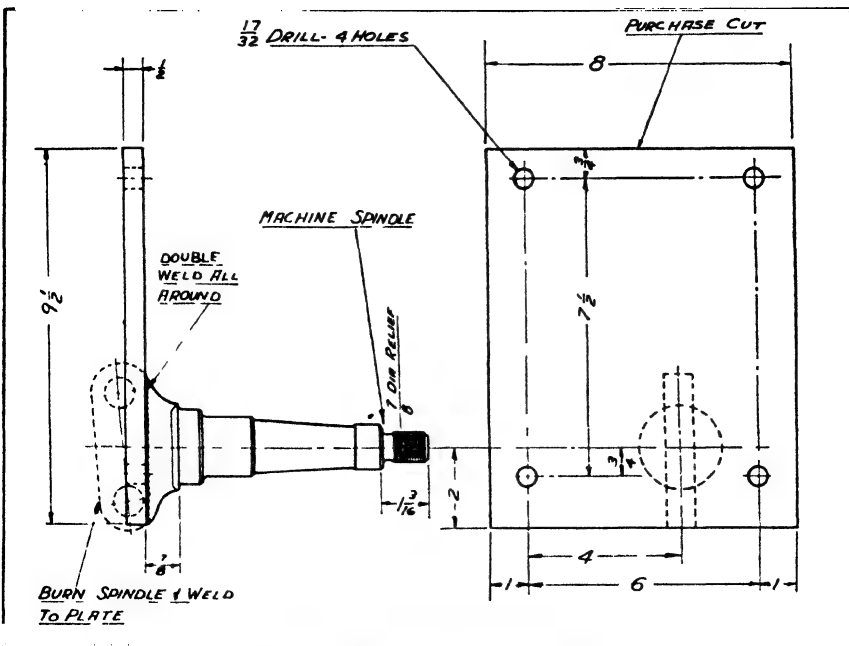



Fig. 7. Wheel spindle and plate.

Here again we are able to meet the special requirements of tread width and axle height without special patterns, tools or equipment by merely fabricating axle extensions that bolt onto the tank side plates where the spindle plates normally bolt. The spindle plates are then bolted onto the outer end of these extensions. These extension axles are made by welding the proper length of 3-inch pipe between two of our standard (½-inch x 8-inches x 10-inches) spindle plates, thus giving the desired tread width. By offsetting the plates where they weld to the respective ends of the pipe we are able to raise the sprayer for additional clearance over the crop rows to avoid injury to plants.

In double checking the advantages gained in our sprayer by the uses of arc welding, I believe you will agree with me that it would not be possible to build our unit either wholly or in part without the use of arc welding. It might be possible but certainly not practical to build a steel tank by riveting

or bolting the heads in. It is even imaginable to picture the nose piece or front part of the frame as riveted together and riveted to the tank by using a little wider and longer material so that there would be more surface on which to rivet the nose piece to the tank, but with such a construction would come the most serious defect found in steel spray tanks. This being the multitude of seams or joints left exposed to the corrosive spray solution. By welding every seam and joint as we have inside and outside of our tank we have settled the question of the durability of the steel tank versus the wood tank by eliminating the possibility of damaging corrosion. In making still further comparisons it would not be possible for us to make use of the standard automotive production spindle if we could not cut it off to the proper dimension and weld it to the steel plate. The only alternative method would be to have a special forging and forging die made which would give us a flanged type of spindle that could be bolted to a steel plate. If we had to do this we would have to invest several hundred dollars in the forging die and then pay more per each for the rough forgings than the price of $1.50 each, which we are now paying for the finished automotive spindle. We would also have to invest in at least one year's requirement of these rough forgings in order to interest any forging company to produce them (our present production averaging from 75 to 100 units per year). Finishing these spindles on an engine lathe together with the drilling and milling operations, would require approximately 6 hours time per pair.

This means that a pair of spindles if forged and machined by us would cost us close to $10. as against $3. per pair plus the cost of the acetylene cutting for the spindle we are using. This saving seems so out of proportion with the total cost of our spindle that we believe it is best to say that there is a very large saving and not attempt to argue actual dollars and cents. But we have as yet not considered any dies cost and this die might easily become obsolete if the wheel manufacturers should change the design of the wheel hub or bearings. This goes back to our belief, proven first, in our former tractor design, that is, to eliminate castings and consequently patterns wherever possible. To carry the argument for welded design in our sprayer still further I ask you simply how else could we possibly mount our agitator bearing plates without subjecting them to the distortion in the tank heads? There is no conceivable practical method by which these agitator or drive shaft bearings could be held in line or lined up at all for that matter. The only possible method would be to bolt or rivet a heavy plate to the tank head using some type of plastic sealing compound between the two in order to take care of the irregularities between the two services. To this plate would then have to be bolted a self aligning bearing which would be very difficult if not impossible to keep from leaking spray liquid. Such a construction would still be subjected to vibrations and bulging which might take place in the tank heads. Whereas, by welding the plate in, we form a very strong and rigid unit. By welding these several parts together to form the finished tank assembly the strength of each part is added to the whole forming a very durable unit, eliminating the necessity of any frame.

Let us refer again to the conventional sprayer. The use of arc welding to replace other means of fastening does, of course, form a more durable joint and usually is less expensive, but cannot be considered as welded design, or the using of arc welded construction to its fullest advantage.

In our design we have completely eliminated this built up frame, axle and tongue, at a saving of 600-pounds of steel and the cost of the wood spray tank. Their frame has to be built strong enough to carry the spray tank

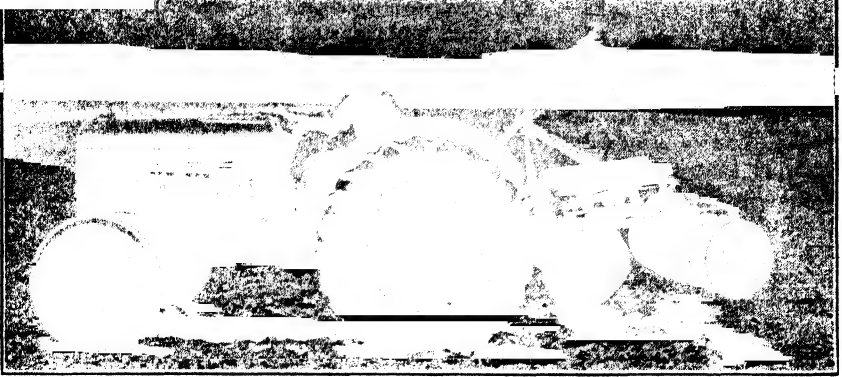



Fig. 8. Tractor disc harrow.

and spray solution load. They are not able to use any of the strength built into their spray tank to an advantage, whether it be made of steel or wood.

Another advantage of our unit and one which cannot be accurately measured is the permanent built-in protection from the very dangerous fast revolving power-take-off shaft. This is accomplished by building the front of our frame over the shaft by welding it to the top of our tank. This is a simple matter in our construction but could not be done on the conventional sprayer. It would be possible for them to build their frame up on the front end by the use of additional structure shapes, but this would make their unit even more awkward and bundlesome looking than it is at present, to say nothing of the added expense. In one county alone, there were 3 deaths attributed to tractor power-take-offs in 1941.

These shafts seriously injure many hundreds each year and many hundreds more are lucky enough to escape by merely having their clothes torn off. In this case welding simplifies the protection so that in giving credit for this increased safety, at low cost it must be given first to welded design, not merely to welding alone, because the sprayer itself was conceived with arc welding as an integral part of it.

The total cash savings accomplished per year cannot be accurately itemized in our case because we can only guess at our competitors cost per each or what our cost would be by other methods, inasmuch as we designed the sprayer to make a full use of arc welding from the beginning. Having learned through our early experience in the manufacture of tractors, that we could make our products better in every respect and for less initial cost and less preparatory expense by using arc welded design to its fullest extent. However, we have one very positive comparison of cost in the total pounds of steel saved and the cost of the spray tank as pointed out. In 1941 we built 68 units—taking the low value of $60 each, this meant a total saving of $4,080. We are also making an actual saving of 46-cents per each on the tank cover assembly or a total saving of $31.28. This also can be attributed to arc welding. In the assumed case the welded wheel spindle versus the bolted one, there would be an apparent saving of $476 for the 68 units in 1941. However, these unfavorable comparisons for other construction methods could be made throughout the unit but could only be made on an assumed basis. Therefore, we believe it best not to make such comparisons but to say only that we are and were certain that the welded construction

was the cheapest and has been used to an advantage wherever practicable.

It may seem a little far fetched when I state as I did at the beginning, that I believe that farm equipment can be built better in every respect and for less money by the use of arc welded design. But I still maintain that I am right. There are a few cases, such as a tractor transmission housing or other gear housings that for various reasons can be cast and machined cheaper than they can be welded. But these are only remote exceptions to the rule—whenever possible build your equipment of fabricated steel and design it from the "ground up" for arc welded design. As a further argument in the favor of arc welding, we are enclosing pictures of our tractor disc harrow, our latest achievement, (See Fig. 8). This unit I have patented and have made contracts for its mass production by a large farm equipment manufacturer. This disc does better work than the present conventional discs and has undergone all conceivable tests from Florida to Arizona to Michigan. It had to prove itself before this company would consider its manufacture because of its unique design. Our 7-foot tandem disc weighs 614-pounds as against an average of the conventional unit of about 900-pounds. Yet this disc penetrates the soil as well as the present type. The disc gangs are similar to the standard construction. The total weight saved and the uniqueness of design being all in the framework. This frame is one solid unit without a bolt in it. It is welded from one end to the other. Each small brace re-enforcing each other brace and holding the disc gangs in a truer relationship than possible in the conventional disc. This frame is stronger and will stand more abusive use than the conventional frame, although we have saved over one half of the weight usually found in the frame, or one-third the total weight of the disc. This unit would not have been possible without the use of arc welded design.

The one reason our disc has been so extensively tested by this farm implement manufacturer is that they have had to install the arc welding equipment necessary and did not want to do so until thoroughly convinced. They are still back in the horse and buggy era of implement design—still bolting steel to castings to more steel, etc., in order to make connections. However, this company has already started to re-design their implements with small amounts of arc welding appearing here and there. But it will be several years, if ever, before they eventually arrive at true arc welded design.

How much better off both they and the farmer would be if they would scrap their present design of implements—clean the cobwebs off of their drawing boards and design for truly arc welded construction.

Chapter XXXI—Arc Welded Bicycle Racks

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Subject Matter: Stress is laid upon the possibility of concealing welds in the construction of "open articles" where good appearance is desired. The cost of a riveted rack used by a telegraph company is compared with that of a welded rack of the same general design. A design is presented for a rack of entirely different appearance, together with an estimate of cost.

As a subject for arc welding, a bicycle rack would hardly be foremost in a person's mind. Arc welding is primarily thought of as a means of making a long continuous joint, a repair or a permanent addition to an iron or steel article. Arc welding possibilities are frequently overlooked in the design and construction of open articles having small and in some cases many joints. A bicycle rack is an example of an open article with many joints.
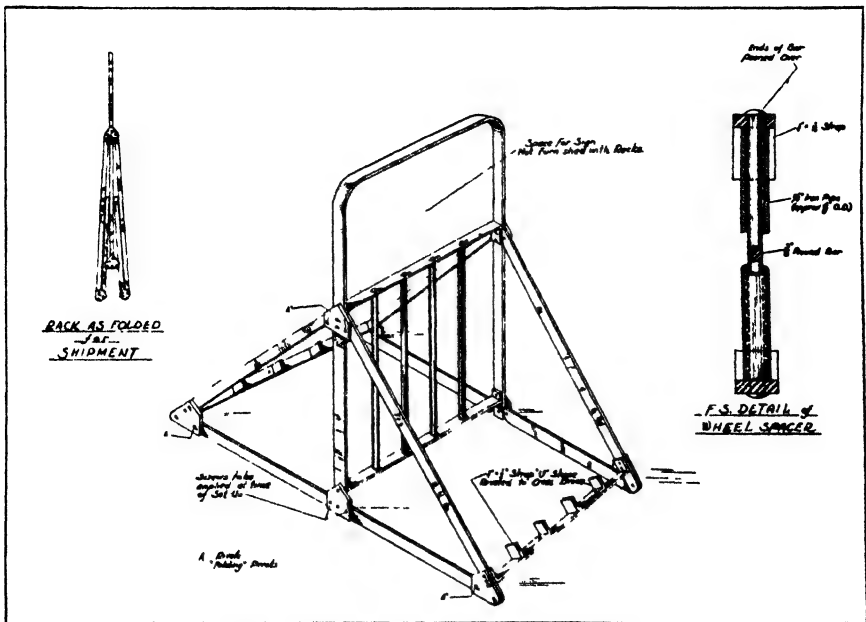
Fig. 1. Bicycle rack, riveted construction.
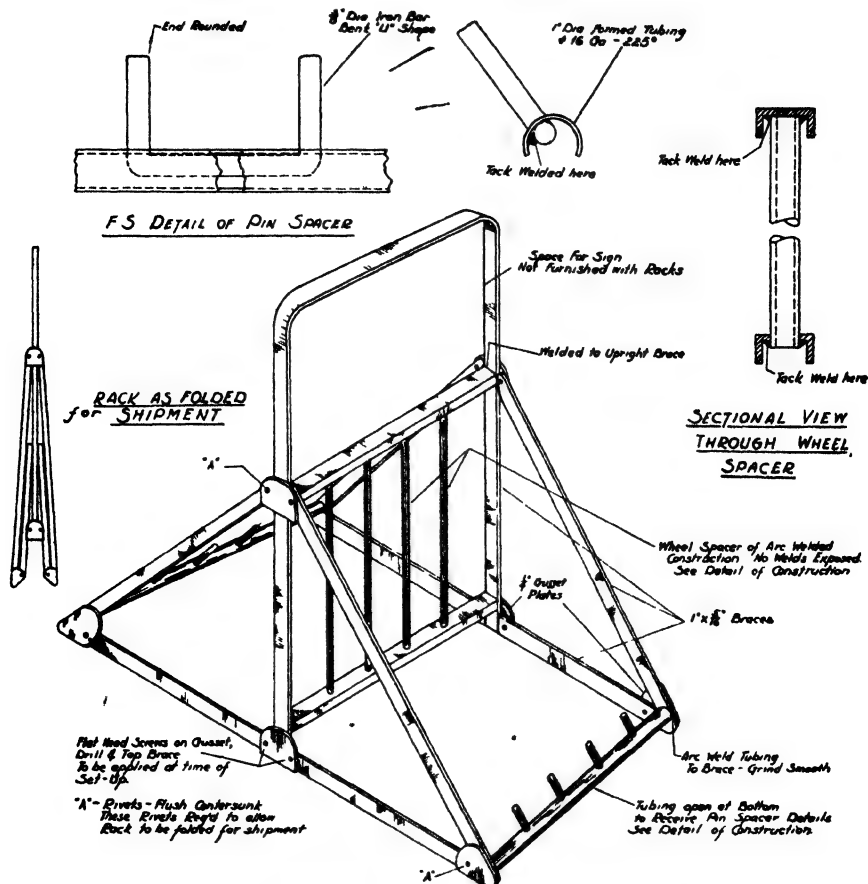
Fig. 2. Bicycle rack, arc welded construction.

The necessity or cost of grinding welded surfaces is often considered a barrier to the use of arc welding when appearance is of importance. Too frequently, the possibility of hiding the weld is overlooked. With but few exceptions, the welded joints used in the bicycle racks, as described in this paper, are hidden.

Arc Welded Bicycle Racks—The subject of this paper is divided into two sections, both related to the single object of improving the design and construction of bicycle racks by arc welding. Under the first section are discussed the economies and improvement by arc welding in the construction of a bicycle rack for telegraph messengers. Drawings, Figs. 1 and 2, showing the construction of the standard riveted type and the new arc welded type, respectively, are included under this section. The second section is concerned with the design of a modern, all purpose bicycle rack of tubular construction, arc welded throughout as shown on drawing, Fig. 3.

Improvement of Telegraph Messengers' Bicycle Rack—The bicycle rack shown on drawing, Fig. 1, with minor variations and alternate construction, has been standard for some years. With the exception of the wheel spacer assembly of pipe and rod with peened ends, the joints are of riveted con-

struction. Screws are used for fastening the bottom braces to the central gusset plates to allow the rack to be folded for shipment.

Drawing, Fig. 2, shows the same rack, arc welded at all joints with the exception of the necessary pivoted joints for folding. Flush rivets are used at the top and lower end plates and flat head screws are used at the central gusset plates in keeping with the smooth clean appearance of the rack as a whole.

The construction of the wheel spacer assembly may be of interest from the standpoint of the use of the hidden weld. The tubes or pipes are arc welded to the under side of the upper cross channel. Holes are punched through the web of the lower cross channel to allow the tubes or pipes to protrude through the holes approximately ¼-inch to provide a substantial welding surface. None of the welds require grinding inasmuch as they are all below eye level and are therefore hidden. The wheel spacer assembly has a clean finished appearance compared with the peened rod ends on the spacer assembly of the standard rack.

The pin spacers, for engaging the bike wheel to the rear of dead center, are also applied with hidden welds. In this case, a formed 1-inch shift tube of approximately 225 degrees is employed as a cross brace. The pins consist of ⅜-inch rod, formed into a "U" shape, placed into punched holes in the tubing. Welds are again hidden on the under side of the tubing and therefore require no grinding. The split tubes are low and therefore require but slightly more than a half round periphery to produce a modern round tube effect.

Other hidden weld joints include the fastening of the wheel spacer assembly and split tubes to the end framing or braces. The gusset plates are arc welded to the braces by conventional arc welding. No excessive grinding is required at these joints, depending to a great extent on the experience and technique of the welder. The gusset plates are varied from those of the standard rack in keeping with the smoother, more finished effect invariably produced in an arc welded design.

Figures on Savings in Construction by Arc Welding

Contract cost of standard riveted rack..$ 7.50

Over a period of a few years these prices have varied from $6.50 to $8.50 in average quantities of 400, a normal year's requirement.

Average quotations on new arc welded rack....................................$ 6.00

The arc welded rack was designed in 1941 and the quotations were received in the latter part of the same year. No contract has been placed because of priorities and the established policy of the company using the racks to buy only in cases of extreme necessity any articles made of critical materials. The quotations are from equivalent manufacturers and are therefore comparable.

Saving in cost of each arc welded rack as compared with the standard riveted rack, $1.50 or 20%.

Annual saving by our company on 400 units..................................$600.00

Referring to figures on offices and agencies having messenger service, it is estimated that from 12,000 to 15,000 racks, of the standard riveted type shown on drawing, Fig. 1, and other racks to meet local needs and conditions of service, are in use by the same company. The use of the new arc welded

rack as shown on drawing, Fig. 2, would result in total savings of approximately $20,000 to the one company alone.

It would of course be very hazardous to attempt to estimate the total number of bicycle racks of similar nature in use today. In any city, town or community, we see stores, service companies and other business establishments using bicycle racks in numbers at least equivalent to several times those used by our telegraph company alone. While reluctant to use figures arrived at without benefit of statistical data, it appears logical and conservative to state that the total economies, which could be realized by the general use of an arc welded rack of the nature described, would greatly exceed the $20,000 for one company alone and probably would amount to several times that figure.

Tubular Bicycle Rack of Arc Welded Construction—Modern design practices are adhered to in the determination of suitable lines for the rack shown on drawing, Fig. 3. Tubing is modern for furniture, stands, racks and many other articles of such nature. It lends itself readily to the use of curves for graceful lines and strength. The end frame is a continuous curve with a slight bow at the top running into half circles at either side to match the front wheels of bikes alternately and oppositely placed in position. The half circles run into a reverse bow at the bottom to prevent "rocker" action and to provide a suitable mounting for the lower cross brace of the wheel spacer assembly.

At a glance, the rack appears to be of the conventional, arc welded, tube or pipe construction. On study of the details we note, however, that hidden welds are employed at practically all joints. The construction of the wheel spacer assembly is similar to that of the messengers' bicycle rack. Formed split tubing is employed for the upper and lower cross braces with the vertical tubes protruding through punched holes in the lower cross brace. At both top and bottom joints the vertical tubes are tack welded to the under surfaces of the horizontal tubes or cross braces. The welds are thus hidden and require no grinding. If the tubes were joined in the usual manner by welded surface contact, the welds would require grinding. Grinding would not only weaken the joints but would entail an expensive operation considering the construction to free movement of the grinding wheel by adjacent uprights. The construction of the pin spacer details, consisting of ⅜-inch rod bent "U" shape and welded to the under side of the split tube cross brace, is the same as that of the messengers' rack.

Application and Use—With rubber shortages and gas rationing so prominent in the news and so closely woven into the rapidly changing pattern of our daily routine, it is needless to furnish proof that use of the bicycle is rapidly expanding. What has been the pride of the American boy, is becoming the means of transportation of his father. Racks will be required for storing the bikes at railroad stations, factories, public buildings and innumerable places.

The rack shown on drawing, Fig. 3, may be considered in the category of a general purpose rack. It is modern and in keeping with the fixtures and appointments of a better grade railroad station, municipal building, library and other public buildings. The cost is not prohibitive for factories and business establishments where a sturdy, serviceable rack would be particularly desirable. The end frames are standard for all racks. The wheel spacer assemblies and cross braces are designed to be furnished in a few standard lengths of 4-, 6-, 8- or 10-feet. The drawing shows how the rack may be quickly set up and assembled when shipped "knocked down".

Cost of Modern Tubular Rack

Cost of material for 6-foot rack.

2—End Frames, 11-ft. each, 1″ dia. × #16-Ga. Welded Tubing, 22-ft. @ $.133/ft.	$ 2.92
4—Cross Braces, 6-ft. each 1″ dia. × #16-Ga. ¾ Round Special, 24-ft. @ $.12/ft. (estimated)	2.88
22—Uprights, 1′-4″ each, ½″ dia. × #16-Ga. Welded Tubing, 30-ft. @ $.108/ft.	3.24
22—Pin Spacers, 11 each side of rack, ⅜″ Rod Approx. 8″ long, 16-ft. @ $.018/ft.	.29
8—Joining Rods, ⅞″ dia., 3″ each 2-ft. @ $.19/ft.	.38
Incidental material, tube filler for bending, welding material etc. (Estimated)	1.00
Total Cost of Material	$10.71

Cost of Labor.

Estimated Cost of Cutting and Bending Tubes, Punching, Drilling and Tapping for 8 Assembly Screws (including Machine Set-Up Time) 1½-hrs. @ $2.00/hr.	3.00
Estimated Cost of Welding and Grinding 1-hr. @ $2.00/hr.	2.00
Fitting and Incidental Labor	.79
*Spraying with Enamel & Baking Oven Time, including Material	1.50
Packing for Shipment including Material	1.00
Total Labor, Painting and Packing	$8.29

Total Cost: Total Cost of Rack including Material and Labor ($10.71 + 8.29) .... $ 19.00

*Chromium Plate would be preferable but as a critical material its use would not be justified or proper for this purpose.

The above figures are based on estimates in reference to labor costs but they appear conservative especially if several hundred units are involved. The figures were reviewed by two manufacturers who considered them reasonable. They also advised that the racks could readily be manufactured in quantities of 500 at $23.75, which will allow a margin of 25 percent for waste, overhead and profit.

No direct comparisons on arc welding and other construction methods on the modern tubular rack are available. If arc welding as compared with riveted construction can effect a 20 percent reduction in selling price on a messengers' rack, the reduction in the tubular rack would be at least as great or greater because the joints must be cleaner and smoother inasmuch as they are more noticeable. On this basis, arc welding on the modern tubular rack would effect a unit saving of $4.75 or 20 percent of the selling price.

Economies and Advantages by Arc Welding Bicycle Racks—We have already indicated that gross savings greatly in excess of $20,000 and very probably several times this figure, may be attributed to the use of arc welding on bicycle racks of the type used by telegraph messengers. The rack serves a dual purpose in the nature of a holder for bicycles and as a stand or frame for a commercial sign. In either case, the use of arc welded construction improves the appearance by making it a smoother, more substantial and finished looking unit.

Fig. 3. Bicycle rack, tubular arc welded construction.

We have submitted a modern design for an article of wide application and the many advantages of arc welding in the construction of such an article. By comparison with the messengers' rack we have indicated unit savings of $4.75 in the construction of a modern tubular bicycle rack by using arc welded joints throughout. As a striking object of thoroughly modern lines, any joint but a smooth joint, or any surface but a smooth surface would be decidedly out of place. Any screw head, rivet or peened rod end would definitely detract from the attractive appearance and functional characteristics of the design. The rack is suitable for places where "better grade" objects are expected as well as for places where cost is of primary importance.

In arriving at figures for the applications and use of the modern, tubular, arc welded bicycle rack, we could refer to railroad time tables and add the stations, or a register of manufacturers and add the number of factories, or an index of cities and towns with public buildings and meeting places, or a church directory and add the number of churches. Not counting the applications which would probably be overlooked, the total would undoubtedly run into high figures. The gross savings by arc welding would amount in dollars to 4.5 times these figures.

As far as arc welding construction methods are concerned, nothing previously unknown has been developed. The hidden weld with resulting elimination of grinding costs is responsible to a great extent for savings effected by arc welding. While not new a wider application of the hidden weld in the design of other articles of open construction would in many cases result in similar economies.

Chapter XXXII—Redesign of Oil-Gas Furnace

By LEMUEL J. HARRIS
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Lemuel J. Harris

Subject Matter: The purchase of a welder inspired this oil and gas furnace manufacturer to redesign two parts of the furnace. The radiator outlet was changed from a bolted-on casting to a welded steel thimble. The saving was $.89. The furnace was supported by 3⅜-inch pipe legs with flanges on the bottom. Several castings were necessary to fasten the legs to the furnace and stiffen the rather weak pipe legs. A stamping was designed to replace the pipe and castings. This change saved $.39 or 48% per furnace. The total saving during 1941 was $1,920 in producing 1,500 units.

Upon purchase of an arc welding machine by my company, I thought it might be advantageous to redesign some parts of our new product, namely: an oil-gas furnace, so proceeded to make such changes as seemed advisable. The following are the steps taken and the results obtained.

In Fig. 1, part number V101, (radiator outlet), you will observe that in the original set-up a casting was used. This casting, weighing 21-pounds, was bolted to two sheets of 16-gauge black iron with sixteen—¼-inch x ¾-inch machine bolts and nuts. Between the black iron sheets and the casting there were two—16-inch strips of 1-inch x 1/16-inch oil burner listing (asbestos) with iron cement to completely seal the joint against combustion gas losses. At the best such a joint cannot be permanent, although it will stand without replacement for years. This set-up was eliminated and replaced by a welded steel thimble V119 as shown in Fig. 2. This thimble with its inside choke was welded as a unit, then welded into radiator sheets as shown. In replacing the casting it was necessary to increase the length of the radiator sheets by 12-inches, which makes a total of 192-square inches 16-gauge black iron sheet. To this is added 218-square inches 16-gauge which is rolled to make the radiator outlet and baffle. To assemble this required 37-inches welding which was made with ⅛-inch rod. Welding time 5 minutes 30-seconds, cost rod $.01. Toal cost weld and rod $.07. Sheet iron added 6½-pounds @ .025 = $.16⅖. Total cost $.2325.

Against this in the old set-up were the following costs: 1 wood pattern labor $58.00, material $8.50. One metal pattern labor $78.00, material $10.50. Molding cost labor only $.36, material grey iron, 21-pounds, $.015 per pound, at spout $.315, sand blast $0.15, grind $.02, drill 16 holes 17/64" drill $.06. Total cost of casting ready to assemble, each $.77. In order to assemble this casting to the radiator sheets the sheets had to be drilled. Sixteen holes 17/64-inch @ $.03.

In assembling, 32-inches of 1-inch x 1/16-inch O.B. listing is used $.045, sixteen—¼-inch x 3-inch round head machine bolts, nuts and washers $.08.
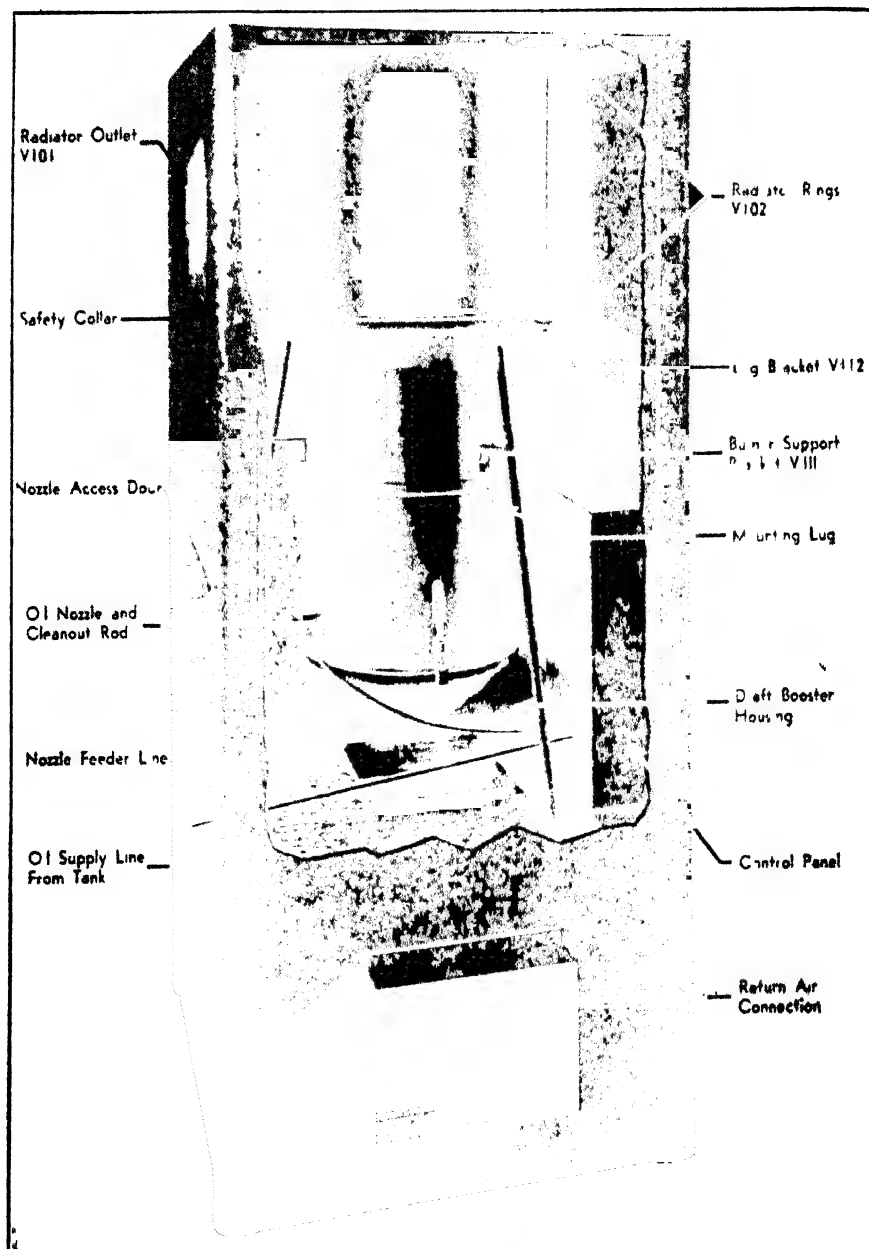
Fig. 1. Cut away view of the oil-gas furnace.
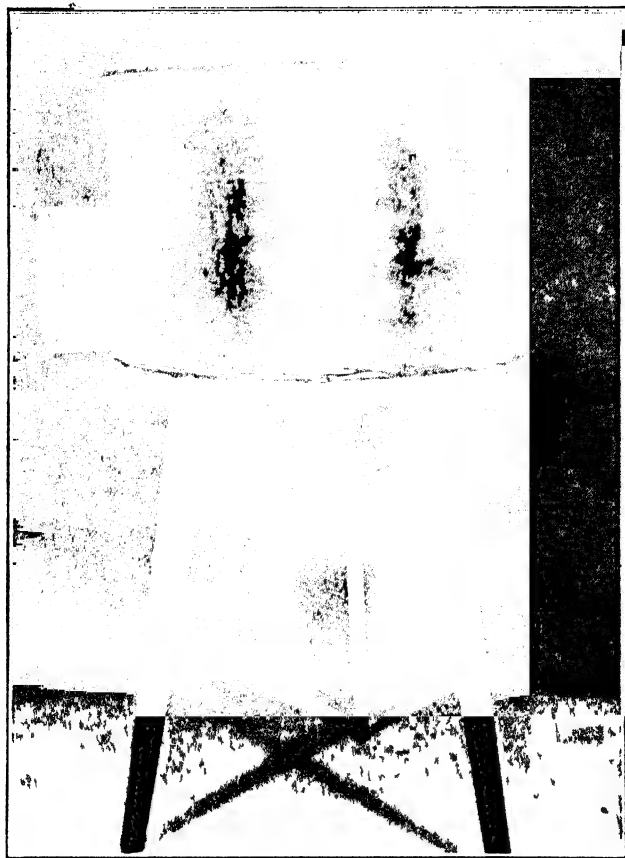
Fig. 2. Arc welded construction.

Assembly cost $.20. Total cost material, labor $1.125. This cost has been arrived at without figuring the life of the patterns and their cost. The patterns were used only to show the initial cost involved to produce the first casting, which becomes unnecessary by use of arc welding. Total cost, old method $1.125. Change in method—$.2325—a saving in the first steps of $1.125—$.2325 = $.8925.

The second step of progress was accomplished by replacing 9 castings. In Fig. 1 you will notice the furnace combustion chamber and radiator are supported by three—28-inch x ⅜-inch heavy-duty pipe legs. The bottom of the pipes resting on three cast iron leg sockets part V105, Fig. 3. These leg sockets are to prevent the pipe from cutting through the sheet iron on which they rest, also to prevent their spreading Part V111 burner support also cast iron, Fig 4, three required, are stiffener brackets with a double purpose. Lower half of bracket support burner, Fig. 4. Leg bracket V112 cast iron, Fig. 1, three required, each have a 7/16-inch stud cast in their bodies, which are inserted into the top end of the pipe. This completes the old type of set-up.
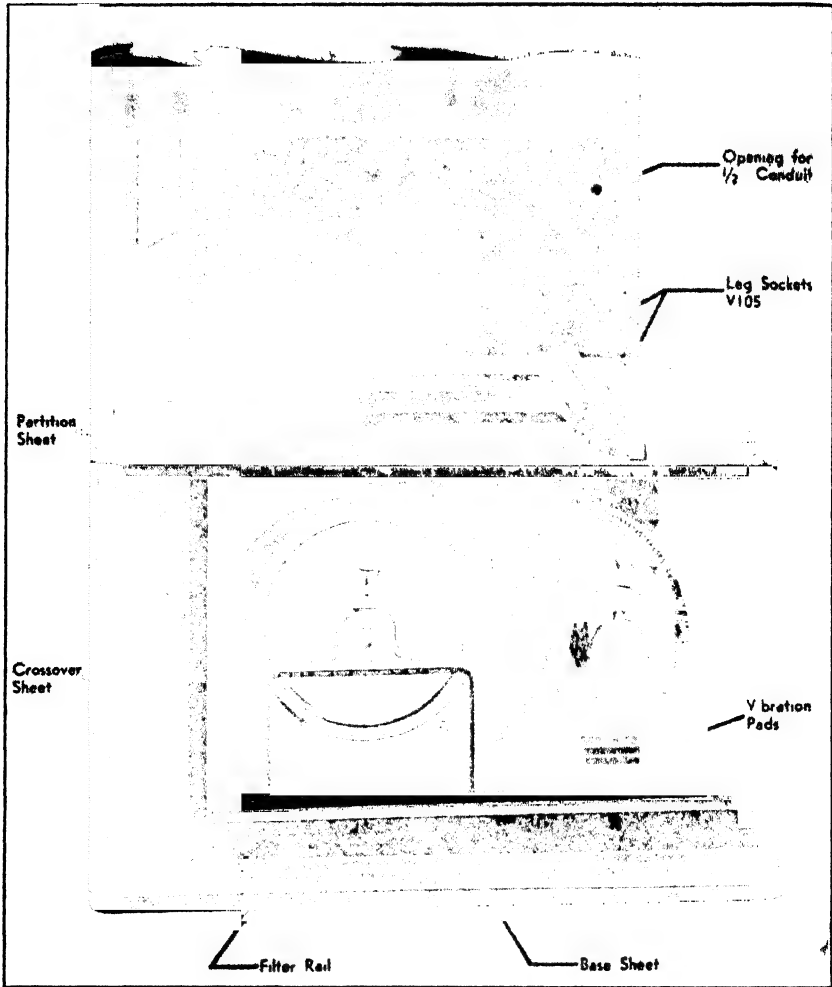
Fig. 3. Cut-away view of base section.

This set up requires, as shown in Fig. 5, three—28-inch lengths heavy-duty black pipe, cost $ 28 Cutting labor $ 015

3 leg sockets V105 Drill	6 holes 13/64	Cost..........	$ 015
3 burner support V111 Drill	6 holes 17/65	Cost...	.025
	3 holes 37/64		
3 leg brackets V112 Drill	6 holes 17/64	Cost	.02
	3 holes 5/16		
	3 Studs, Labor and material		.06

Assembly requires six—3/16-inch x 5/8-inch sheet metal screws, twelve—¼-inch x ¾-inch machine bolts and nuts and washers, value $ 075. Assembly
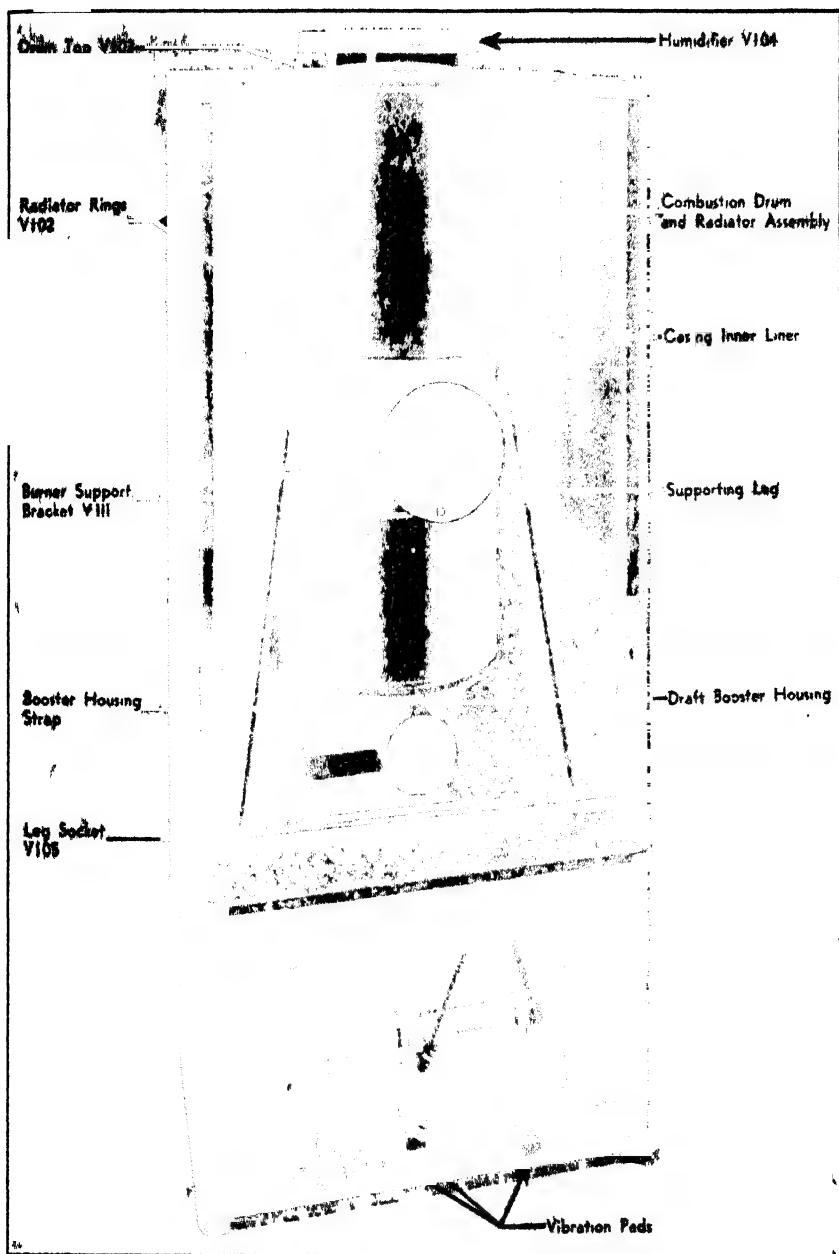
Fig. 4. Additional details.
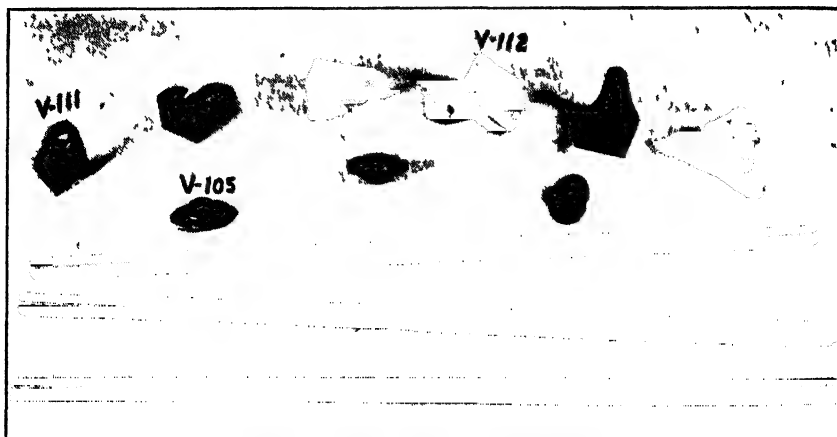
Fig. 5. Parts used in construction.

cost \$.20. Labor and material \$.069, to which must be added molding cost etc. Pattern cost for the three different castings:

	Wood patterns	\$23.60
	Metal working patterns	76.64
	Material cost	13.00
Molding cost:		
	Leg spaces	.0075
	Leg bracket	.03
	Burner support	.015
Metal at spout:		
	$4\frac{3}{4}$ lbs. @ .015	.07
	Sand blast	.0025
		.1250

Total cost labor and material \$.69 and \$.1250 = \$ 8150

The old method as shown in Figs. 1 and 4 was replaced by V120, Fig. 2. This set-up required 3 channel-shaped legs as shown in Fig. 2. In each leg, there are 5 holes, two punched out for the $\frac{1}{4}$-inch machine bolts that fasten them to the combustion chamber, one in the bottom $\frac{18}{64}$-inch for a sheet metal screw, one at the off-set $\frac{17}{64}$-inch for the burner support mounting lug screw as shown on Fig. 1. One $\frac{17}{64}$-inch hole at the top where the lower radiator ring V102 is held in place by tie rod—not shown but opposite one shown in Fig. 2.

This leg is blanked, punched and partly formed in blanking, piercing and forming die. Cost of die, labor and material \$250.00. Cost of 16-gauge sheet metal for 3 legs @ .09 = \$.27.

There is $4\frac{1}{8}$-inch weld required on 3 legs. Finish form and weld. Time and material \$.12. Secondary assembly time has been eliminated as legs are now assembled when furnace is installed as there are no castings involved and is included in the installation final assembly. Six—$\frac{1}{4}$-inch x $\frac{3}{4}$-inch machine bolts, nuts, and washers and three metal screws, cost \$.0375. This makes

a total cost labor and material less die cost $.4275 against $.815 under old method. Results: a much better, more stable leg at less cost, approximately 48 per cent saving.

All costs in this report are actual less overhead expense. 1500 units were made in 1941 at a total saving of $1,920 over old method by using electric welding in construction. Die costs were only shown for comparisons, not in figuring actuals. Pattern cost less overhead $269.24. Dies cost less overhead $250.00.

Chapter XXXIII—Bottle-Washer Redesigned for Welding

By Ernest R. Becker

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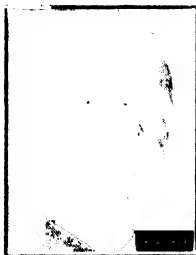
Ernest R. Becker

Subject Matter: Bottle-washing, machine-conveyor assemblies have been made mostly of castings riveted to chain carriers. The riveted assemblies were generally distorted enough by buckling of the rivets to make the accumulated error too great for good performance. The carrier ends' cupholders were redesigned for stamping and assembly by welding. Jigs were used for the welded assemblies which also proved to be adequate for inspection. If the part could be removed from the jig by hand, it was within the tolerance demanded and no further inspection was necessary. This redesign of the two parts saved $95.79 per machine and required less power to drive the machine due to lighter moving parts.

The project described in the following analysis covers improvements and economies achieved in the manufacture of bottle-washing machinery through the substitution of steel sections fabricated by arc welding in place of cast iron sections formerly used.

The type of machine under analysis, a bottle washer, is used by the brewing and beverage industries for the continuous and automatic washing and sterilizing of glass beverage bottles.

Fundamentally, the apparatus consists of a large tank, sub-divided into compartments containing the cleaning, sterilizing, and rinsing solutions, and having attached thereto the necessary automatic machinery for receiving dirty bottles, conveying them progressively through the various solutions, thence through successive stages of exterior and interior brushing and rinsing; finally depositing the clean and sterile bottles on a conveyor leading to automatic filling and crowning devices.

The mechanism for transporting the bottles through the machine consists of an endless conveyor made up of adjacent transverse channel sections, each providing a series of openings or pockets and connected at their respective outer ends to endless parallel strands of heavy conveyor chain. The connection between channel sections, or carriers, and the chains has heretofore been accomplished through the medium of cast iron carrier end pieces, riveted to the carriers and fastened to the chain links by bolts. Buckling of the rivets in their holes introduced misalignment between the carrier ends and carrier sections of such magnitude that rejection of finished parts averaged nearly 5 per cent. Furthermore, it was often necessary to remove completed carriers from finished machines at the final operating test run because of accumulated error on several successive carriers.

Redesign of Carrier Ends—After several unsuccessful attempts to maintain closer tolerances without adding unduly to the manufacturing costs, it was finally decided to redesign the carrier end for welding, instead of riveting to the channel sections. This naturally required a change of material from cast iron to cast steel or to a steel stamping.

A preliminary estimate indicated that a steel stamping, so designed as to eliminate all machining operations, would effect a considerable saving over the use of castings; consequently work was begun along this line.

In the final design the carrier end consists of two pieces: a cup or body of 12-gauge deep drawn steel and an attachment lug of 8-gauge steel, both punched and drawn to a suitable form and arc welded together into a unit.

The punching, forming, and drawing operations for each part are performed in progressive dies to tolerances closer than could be economically maintained in the machining of the original cast iron parts.

The attachment lug and body are joined by arc welding, in a fixture which holds the parts in exact alignment, resulting in a finished piece of such accuracy that in the manufacture of 20,000 pieces to date, there has not been a single rejection.
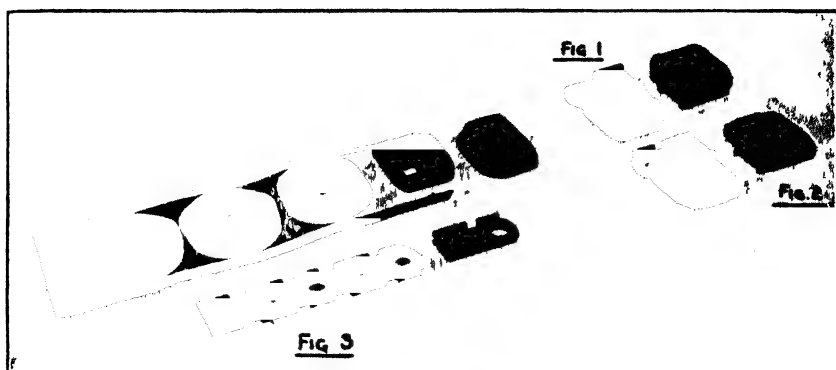
Fig. 1. Cast iron carrier and base front and rear views. Fig. 2. The redesigned carrier end base. Fig. 3. Progressive punching and forming operations.

All necessity for separate inspection has been eliminated, since the welding fixture itself constitutes an inspection gauge in that any part which can be removed by hand from the fixture is necessarily well within the required tolerance limits.

In the attached illustration, Fig. 1 shows the original cast iron carrier end piece, front and rear views; Fig. 2 shows corresponding views of the redesigned part; while Fig. 3 indicates the progressive punching and forming operations in the fabrication of the component parts.

Welding the carrier ends into the carriers is performed in a specially designed roll-over fixture in which the end pieces are held in true relative alignment and maintained at an exact distance from the end pockets of the carrier sections. Here again, the welding jig likewise serves as an inspection fixture.

Because the riveting operation required with the original design introduced misalignment of the end pieces, which in turn was responsible for binding of links in the carrier chain, it was necessary to provide a special self-aligning connection between the end castings and the chain links. This consisted of a spherical counter-bore in the casting to receive a plano-convex washer; the combination forming a modified universal joint between the end castings and the chain side bars. Since the welded design was adopted, no such provision has been found necessary because of the inherent accuracy of the construction.

Photographs of a complete carrier with the cast iron ends, as well as one with the fabricated end pieces, are shown herewith, (See Figs. 4 and 5).

Original estimates on the cost of this new design compared to the known cost of the standard part indicated that the expected saving due to the new method of manufacture would approximate 6c per piece. The actual saving accomplished is shown by comparison of the following figures:

Cost Data—Cast Iron Carrier End Piece

Material—1½ lbs. C. I. @ 7c			10.50c
Drilling all Holes	2.40 minutes		
Spherical counterbore	.66 minutes		
Inspection	.25 minutes		
	3.31 minutes	(@ $1.54 per hr.)	8.50c
Cost per piece			19.00c
Riveting to carrier channel—2.2 min.		(@ $1.60 per hr.)	5.90c
Final Cost—Assembled—per piece			24.90c

Cost Data—Steel Welded Carrier End

Material (including scrap) 1 lb. Annealed Steel Sheet @ 2.28c			2.28c
Body			
(Shear strips	.05 minutes		
(Blank, Draw, Punch	.31 minutes		
Lug			
(Shear strips	.04 minutes		
(Blank, Draw, Punch	.60 minutes		
	1.00 minutes	(@ $1.64 per hr.)	2.73c
Weld (on Special Fixture—1.00 minutes		(@ $2.07 per hr.)	3.45c
Welding Rod			.20c
Cost per piece			8.66c
Weld End Piece to Carrier Section 1.4 minutes		@ $2.07 per hr.)	4.83c
Welding Rod			.40c
Final Cost—Assembled—per piece			13.89c

Cost Difference (24.90c-13.89c) in favor of Welded Construction..11.01c
This difference of 11.01c each represents a saving of 45 per cent in favor of welded construction.

Note: All hourly rates based on direct labor plus overhead.

Since a bottle washer of average size has approximately 300 carriers, representing 600 end pieces, the saving accomplished through the design change on this particular piece averages $65.64 per machine.

As stated in the preliminary description of a bottle washer, the carriers are moved progressively through the machine. This motion is accomplished by an intermittent pusher mechanism, operating at approximately ten strokes per minute. The lighter construction of the welded carrier ends effects a saving of 1½-pounds per carrier, or a total of 450-pounds in the complete bottle conveyor, which in turn results in a very considerable reduction of the
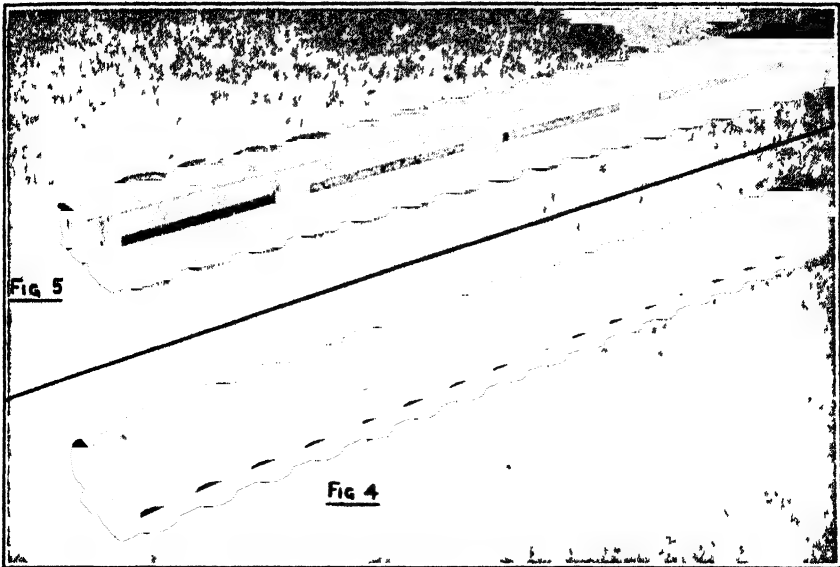
Fig. 4. Complete carrier with cast iron heads. Fig. 5. Fabricated carrier.

power required to drive the machine. Equally important is the reduction in wear of the various moving parts of the drive mechanism and of the conveyor chain itself.

Redesign of Cup Holder—Further investigation of other members of the machine led to an analysis of the lower cup holder design. This lower cup holder is a heavy casting (375-pounds) of I-Beam cross-section carrying a double row of spring-supported centering cups; the whole assembly mounted between guides and being reciprocated vertically through the medium of cam-actuated lifting arms. Fig. 6 shows one of these castings with several of the centering cups in place.

The revised design, illustrated in Fig 7, consists of upper and lower channel plates arc welded to a center web member to form an I-Beam section. Stress calculations indicated that 8-gauge steel plate for the upper channel and for the vertical web members, and 10-gauge plate for the lower member would provide a section of ample strength.

Because of the fact that the assembly requires a degree of accuracy higher than is usually maintained in structural fabrication, the problem of warping during the welding operation received special attention. On the first trial assembly, the web member was joined to the upper and lower channels by interrupted fillet welds.

The resulting finished part, although acceptable, showed a definite tendency towards warping, and it was evident that this condition could be expected to become more serious in regular production. A second experiment section was fabricated in which the fillet welds were omitted and the parts joined by "plug" welds. To this end, elongated holes, 3/8-inch wide x 1 1/2-inch long spaced 4-inch center-to-center, were punched along the longitudinal center lines of the upper and lower sections, and the center, or web member, was increased from 8-gauge plate to 1/4-inch in thickness. The material of this section was also changed from hot rolled plate to a cold rolled steel bar for

the sake of increased accuracy, and in order to provide a sufficient foundation for the "plug" welds.

After tacking the parts in place, the welds were made, first filling in two slots in the upper member, then welding two corresponding slots in the lower member, alternating between the top and bottom members until all welds were completed. In this way, heat distribution throughout the three sections was equalized and severe shrinkage stresses avoided. The finished section fulfilled all expectations.
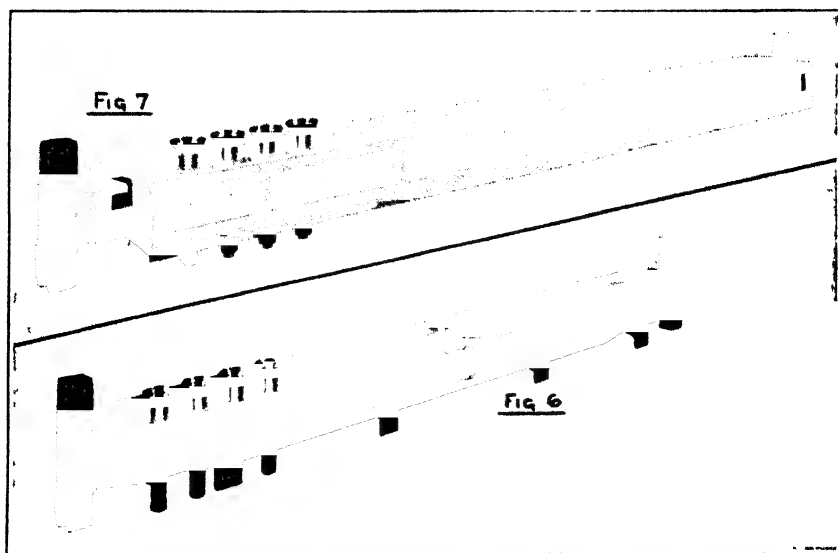
Fig. 6. Casting and Fig. 7 welded design with centering cups in place.

In the original cast iron version, the upper openings for the sliding cups were fitted with bronze bushings pressed into place, whereas in the lower flange no bushings were required; the casting being designed to provide sufficient depth for proper welding surface. In the new design, lacking sufficient thickness of metal to assure a satisfactory press fit, the upper bushings are provided with two drilled ears for hold-down screws and special shouldered and threaded bushings, clamped in place by a retaining nut are used in the lower flange.

A multiple punch assembly for the upper section punches two opposite cup openings, four holes for bushing retainer screws, and one slot for welding at each press stroke; the press being provided with a spacing bar for accurate longitudinal positioning. The same die set, through interchangeable punches, is used for perforating the lower section.

It will be noted that the sliding lugs, or cross-heads, at each end of the cup holder are separate pieces bolted in place, whereas it might seem that they should have been incorporated as a unit part of the design. Available machine shop facilities were the determining factor in this case, since the separate construction permitted the use of a standard milling machine for finishing, thus releasing a large machine of greater earning capacity for other urgent operations.

The welding fixture was designed to hold the component parts in accurate

alignment during welding, while incorporating easy and rapid positioning on "roll-over", to allow of alternate top and bottom welding, as noted previously.

There follows a comparison of actual manufacturing costs of the two units.

In tabulating these costs, the bronze bushings in the upper flanges of both the original cup holder and the improved design have been deliberately omitted from the calculations. It so happens that the cost of fabricating and assembling the original bushings is almost exactly the same as the corresponding costs on the new style; consequently, omitting both from the figures permits a more direct comparison between the cost of the two units.

Cost Data—Cast Iron Cup Holder

Item	Time	Rate	Cost
Material—375 lbs. C.I. @ $.088			$33.00
Plane Top	1.9 hrs.	@ $1.90 hr.	3.61
Mill Bosses	2.2 hrs.	@ $1.80 hr.	3.96
Mill Cross-heads	4.6 hrs.	@ $1.80 hr.	8.28
Mill Side Pads	1.7 hrs.	@ $1.80 hr.	3.06
Drill, Ream, Tap	8.5 hrs.	@ $1.90 hr.	16.15
Total			$68.06

Cost Data—Fabricated Steel Cup Holder

Part	Operation	Rate	Cost
Top Plate	Material—55 lbs. @ 2¼c		$ 1.24
12 18/32"	Shear Stock—10 min.	(@ $1.64 per hr.)	.27
× 8 ga.—	Bend Flanges—20 min.	(@ $1.56 per hr.)	.52
7′–2½" lg.	Punch all Holes—50 min.	(@ $1.64 per hr.)	1.37
Bottom Plate	Material—46 lbs. @ 2¼c		1.04
13 29/32"	Shear Stock—10 min.	(@ $1.64 per hr.)	.27
× 10 ga.—	Bend Flanges—20 min.	(@ $1.56 per hr.)	.52
7′–2½" lg.	Punch all Holes—15 min.	(@ $1.64 per hr.)	.41
Web Plate	Material—24 lbs. @ 6¼c		1.50
4 × ¼"	Cut to length—5 min.	(@ $1.64 per hr.)	.14
C.R.S.—			
6′–11¼" lg.			
Side Straps	Material—10½ lbs. @ 6c		.65
16 pieces	Shear—2.5 min.	(@ $1.64 per hr.)	.07
1 × ⅜"	Punch—4.0 min.	(@ $1.64 per hr.)	.11
C.R.S. Bar	Set up and weld—1½ hrs.	(@ $2.07 per hr.)	3.11
5" long.			
End Castings	Material—42 lbs. C.I. @ 9.3c		3.92
(2 pieces—	Layout—.8 hrs.	(@ $1.72 per hr.)	1.38
complete)	Mill Ends—1.1 hrs.	(@ $1.80 per hr.)	1.98
	Mill Top and Bottom—9 hrs.	(@ $1.80 per hr.)	1.62
	Drill and Ream—.9 hrs.	(@ $1.80 per hr.)	1.62
Lower Flange Bushings	Purchased Item—@ .47 each		18.80
40 pcs. complete with nuts.			
Assembly	2 End Castings—.4 hrs.	(@ $1.48 per hr.)	.59
Assembly	40 Lower Flange Bushings—.9 hrs.	(@ $1.48 per hr.)	1.33
Total			$42.46

NET SAVING—$25.60 or 37½%.

Redesign of this part, in addition to the cost reduction pointed out in the tabulation, accomplished a saving in weight of 173-pounds, or 46 per cent.

In the operation of the complete machine, this assembly reciprocates at

the rate of ten cycles per minute, through a travel of 6-inches, actuated by a lifting arm which is counterweighted. Elimination of excess weight permitted a reduction of approximately 130-pounds in the cast iron counterweight, which at 3½c per pound amounts to a further saving of $4.55. Because of reduced weight, there will likewise be a slight reduction in power required for operation, due to diminished inertia of moving parts; bearing life should be substantially increased, and general operation of the machine definitely improved.

Although no radical changes of shape or outline have been introduced, the smoothly rounded edges and straight lines of the redesigned units present a more pleasing picture to the eye, and have definitely improved the appearance of the whole assembly.

Summation

I, Proportionate Cost Saving—The change from a cast iron carrier end, riveted into position, to a steel part fabricated by arc welding, and arc welded into place, accomplished a saving of 45 per cent in final cost of this piece

Redesigning a cup holder from cast iron to fabricated steel, assembled by arc welding, saved 37½ per cent of original cost of manufacture.

II, Estimated Total Annual Gross Savings—(a), Production of bottle washing machines incorporating the members discussed on the preceding pages, in the plant of the Liquid Carbonic Corporation totaled 110 units, during the year 1941. On the basis of $65.64 per machine saved in carriers; $25.60 on the cup holder, and $4.55 through elimination of counterweighting, the total per machine represents $95.79, or an overall saving of $10,536.90 per year; (b), The estimated total production of bottle washing machines of a type similar to the foregoing is 300 units per year. On this basis the substitution of arc welding for other methods of construction in the manufacture of components as discussed herein would accomplish a gross saving of approximately $28,500.

III, Increased Service Life and Efficiency—The saving in power costs realized by reducing the weight of moving parts has been pointed out previously. This of course results in increased efficiency as related to cost of operation. Maintenance costs will be reduced through longer life of bearings, cams, gears, and other parts forming part of the drive mechanism. Reduction of breakage of cast iron sections will reduce shut-down time during operation, which to the bottler is the one most important factor of all.

Chapter XXXIV—Arc Welding of Automatic Can-Testing Machine

By H. B. PETERSON

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H. B. Peterson

Subject Matter: Welding is a logical method for machines needed in limited quantities. Only one testing device was needed to check "ham" cans for leaks. Pattern alone for the machine with cast iron parts would have cost $1,550. Welded construction saved this pattern cost and reduced the weight over cast iron by 1,800-pounds. Previous machines built for testing other cans had used cast aluminum testing pockets. These often leaked and required special peening to stop the leaks. In addition, expensive machining was necessary to make the pockets fit the cans. Welded testing pockets for the cans did not leak and they could be preformed to fit the can. The welds were ground smooth and no machining was necessary.

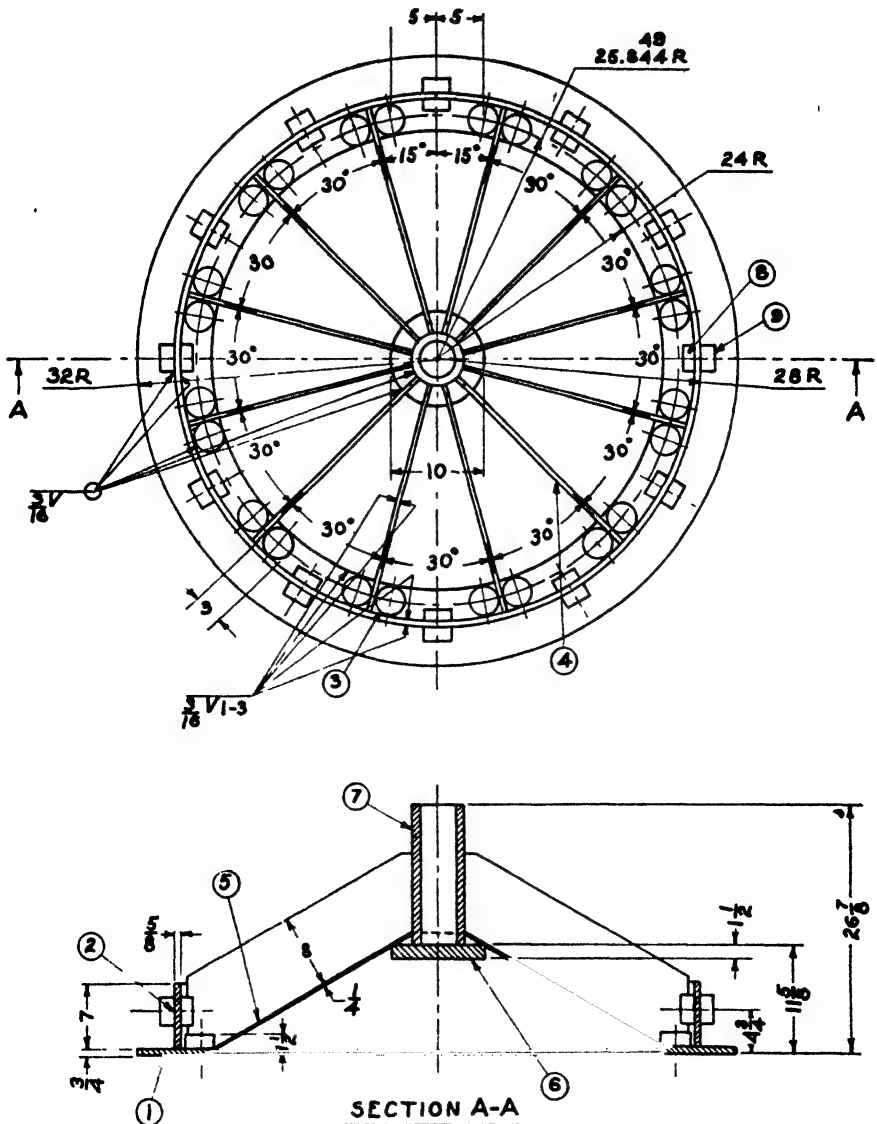
The problem of designing and constructing that "problem child" known as the "one off" machine is one that confronts many designers. The high cost of patterns alone makes the overall cost of the machine prohibitive, especially when it is definitely known that only one unit will ever be constructed and pattern costs must be charged against the machine. Therefore, the logical conclusion for the economical construction of such a unit lies in the adoption of as much welded construction as is practical.

The machine under consideration is a can testing machine, capable of detecting leaks as fine as .002 inches in diameter in an odd shaped can of considerable size. The can is known as the "whole ham can" and is approximately 7½-inches x 10⅝-inches across the major and minor axis, by 5½-inches high. Whole hams are packed into these cans, sealed and cooked. The nature of the product and its rather high cost make it imperative that the can must be practically perfect or spoilage will set in with its resulting losses.

The large size of the can and its extremely irregular shape presented varied problems of machining and construction. Basically, the machine consists of 12 pockets slideably mounted on tie rods between an upper and a lower turret. Rods absorb tension loads incurred in closing the pockets as well as providing guides for the pockets to slide on. The pockets are raised around the can by means of crank arms, which are cam actuated, On surrounding the can, the pocket forms a closed chamber around its periphery, this being known as the testing chamber. Subsequent admission of air to the can provides the testing medium and any leaking can is detected and rejected. The whole process of testing calls for rigid members and air-tight pockets, especially where it is desirable to detect a .002 hole.

The basic members of the machine, that is base, upper turret, lower turret, feed and discharge tables, also feed base, were carefully scrutinized for their design either as cast or as welded construction. The turrets and base are large conical shaped members requiring built up patterns. The estimated cost of these three patterns alone was $1230. The very cost of these patterns immediately turned the design over to welded construction. With the

BILL OF MATERIAL			
No	AMT.	DESCRIPTION	METAL
1	1	6½ O.D.-4½ I.D. 15 LG.	[illegible]
2	1	⅜ PLATE 76×76 LG	M-2.
[illegible]	1	3/4 PLATE 14½×230 LG.	M-2
4	3	1/4 PLATE 17½×31½ LG	M-[illegible]
5	3	1/4 PLATE 4×10 LG.	M-2
6	3	1/2 PLATE 6×10 LG	M-2
7	3	⅜ PLATE 11×13½ LG.	M-2
8	6	3/8 PLATE 5×7½	M-2
9	2	3/4 PLATE 12×15 LG	M-2
10	3	3 DIA. 8 LG.	M-2
11	1	3/4 PLATE 14×20 LG	M-2

Fig. 1. Welding assembly.

BILL of MATERIAL			
NO	AMT	DESCRIPTION	METAL
1	1	3/4 PLATE 64½ x 64½ LG.	M-2
2	1	5/8 PLATE 7 x 175 LG.	M-2
3	24	3 DIA. 1½ LG.	M-2
4	12	3/8 PLATE 8 x 33 LG.	M-2
5	1	1/4 PLATE 56 x 56 LG.	M-2
6	1	1½ PLATE 10½ x 10½ LG.	M-2
7	1	5½ O.D. 3¾ I.D. - 16 LG.	SEAMLESS STEEL TUBING
8	12	3 DIA. 1½ LG.	M-2
9	12	3 DIA 1⅜ LG.	M-2

WELDING SYMBOLS		
TYPE OF WELD	SYMBOL	DESCRIPTION
FILLET	3/16 V 1-3	INTERMITTENT WELD WITH 3/16 FILLET 1 LG. ON 3 CENTERS
FILLET	3/16 V (all around)	ALL AROUND WELD WITH 3/16 FILLET

Fig. 2. Lower turret.

valuable aid of the local welding engineers, the turrets and base were designed in accordance with drawings, Figs. 1, 2 and 3.

The base, Fig. 1, consisted of a 3/4-inch x 15-inch plate rolled into a ring 68 3/4-inches inside diameter and butt welded. Slipped into the ring is a 3/8-inch plate formed and butt welded into a cone and subsequently welded to the ring with 3/16-inch fillet welds. The center is a 6 1/2-inch outside diameter x 4 1/2-inch inside diameter seamless steel tube welded to cone and stiffened by 6 1/4-inch ribs welded to the center and outside ring and intermittent welded to the supporting cone. The necessary connection pads were formed as separate units and welded to the frame as a whole. A reduction in weight from the cast iron design to the welded design amounted to 38 percent.

An additional advantage lies in the fact that the outer ring being used as part of the cam mechanism, is steel, and eliminates breakage which sometimes occurs when a can jams.

The lower turret is shown on drawing, Fig. 2, and upper turret shown on drawing, Fig. 3. The lower turret consists of a flame-cut plate to which the drive gear is attached; to this is welded a 5/8-inch x 7-inch ring, together forming a section. The plate is in turn welded to a 1/4-inch plate cone reaching to the center boss. Twelve 3/8-inch x 8-inch plates form the necessary stiffening ribs. Bosses for the tie rods are welded on as well as the bosses for the pocket raising lever. The weight of the welded construction is 1350-pounds as compared with an estimated 1980-pounds cast construction or a 30 percent reduction. The freedom from breakage in this member is of great importance; therefore the steel construction is vastly superior to the cast construction.

The upper turret is essentially the same design that is flame-cut plate welded to the center cone and with stiffening ribs welded to the cone. Bosses for the tie rods are welded to the flame-cut plate as in the lower turret. The center cone has 12 flame-cut holes to allow passage of air lines to the testing mechanism. The welded upper turret is 875-pounds as compared to the estimated cast weight of 1280-pounds or a 32 per cent reduction.

The various tables for can feeding and can discharging as well as their base are constructed of 1/2-inch steel plate and ribbed up with 5/16-inch x 4-inch straps. Machined surfaces remove any warpage and provide good seating for the various mechanisms attached to them.

All of the structural members were not welded. An exception was in the use of a cast overhead spider, as this member contained the delicate testing devices and valves. However, the supports for the spider were constructed of 6-inch channels with welded flanges at either end and this formed the attachment to the base and spider. One of the channels conveniently became an air reservoir when a 1/4-inch x 5-inch slab was welded to the webs and for its whole length. On cast construction, it is necessary to provide this reservoir as a separate unit requiring support and additional piping. Cast legs were adopted for supporting the can feed table as it is required to house electrical equipment and controls in accordance with the company standards.

Of special interest for its novelty, is the use of welded construction to eliminate a costly and difficult machining operation. This is employed in the construction of the testing pockets which surround the can. The test pocket must follow the contour of the can with only .010-inch to .015-inch clearance over the seam of the can. Normally this necessarily calls for machining. On previous machines, pockets were made of aluminum for

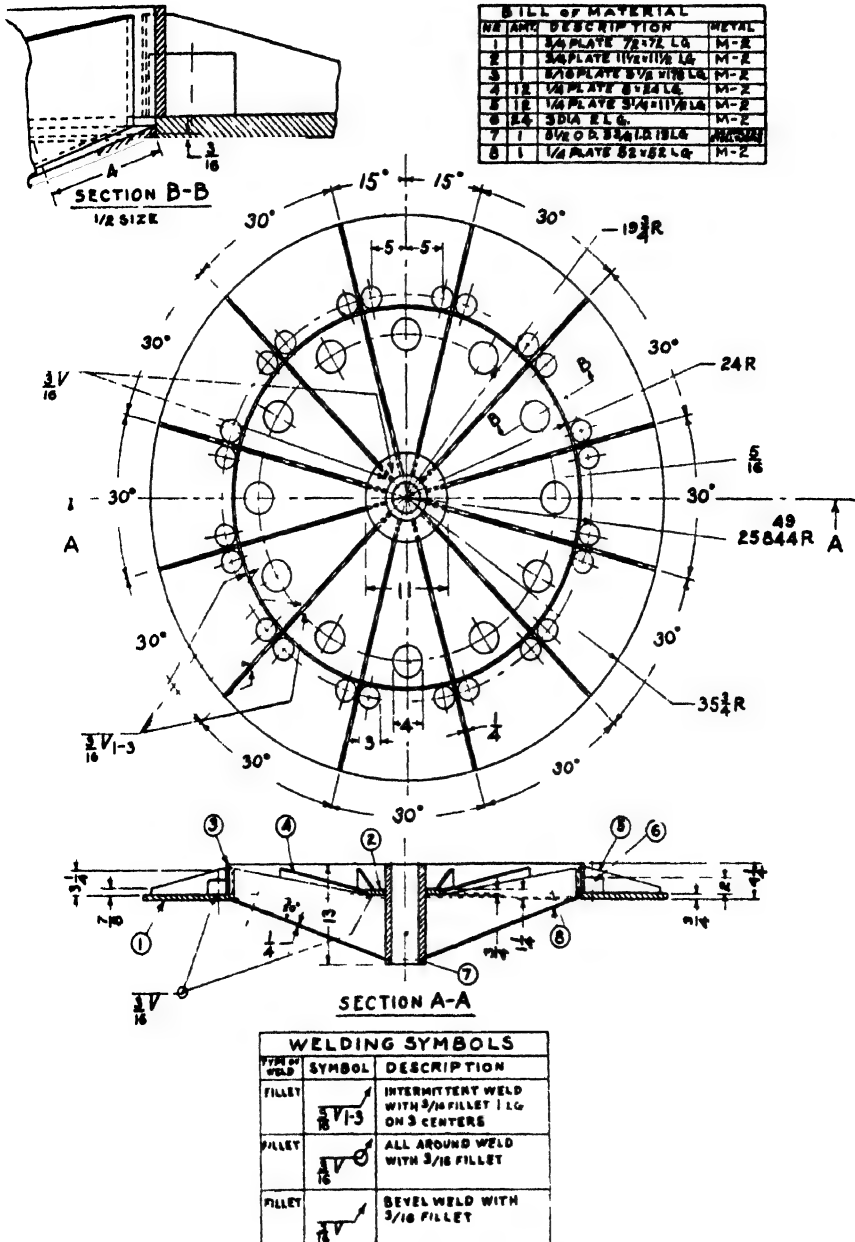



Fig. 3. Upper turret.

easier machining and shaped out to can size. This is relatively a simple job when the can is a rectangular or a round shape. But in the unit under discussion the can shape is irregular, and the shaping operation would be costly and would have to be followed by hand finishing. After considerable study, a welded design was decided on.

The welded pocket consists of a cold rolled steel strip ⅛-inch thick by 6-inches wide by 27-inches developed length, and of dead soft temper. It is welded to a top and bottom flange and to a "V" slide member. The finished pocket is shown on drawings, Figs. 4 and 5 as well as welding assembly Fig. 6. The flanges are flame-cut to size with a light cut taken on the inside on our special cam mills which amounts to only .4 hour per flange. The ⅛-inch thick body is corrugated at two points prior to forming to the "ham" shape. The pocket is really formed on the welding fixture.

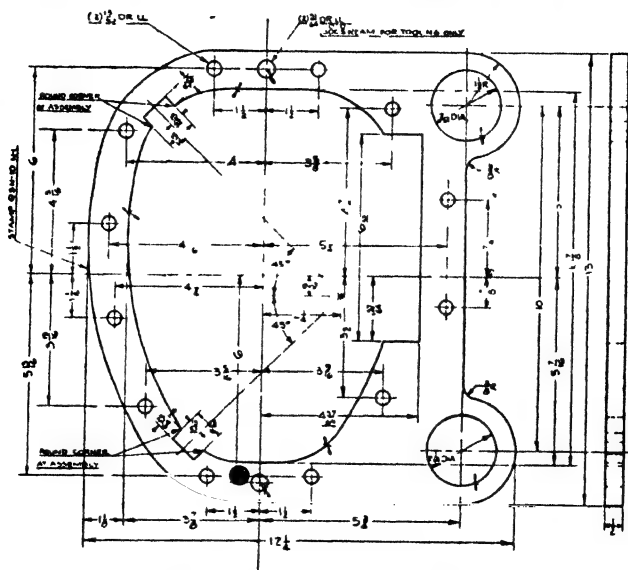



Fig. 4. Chamber flange.

The pocket welding fixture consists of a steel plate to which is fastened a cast iron form which is the exact size of the inside of the pocket. To the form is fastened a "V" block, on which the "V" slide member of the pocket is placed prior to welding. Two pilot pins align the flanges correctly to the cast iron form. In manufacturing, the lower flange is first placed on the fixture, and the "V" slide member next placed on the form. The ⅛-inch x 6-inch body is now ready to be placed in form. The body has been processed to the extent of having two corrugations pressed in the sides for clearance of the pull down fingers. One end of the body is first welded by tacking to the outside of the "V" slide member and then wrapped around the form. The dead soft temper of the body permits the forming operation to be easily done. The free end of the body is inserted into the "V" slide and then pressed down into the lower body flange. The end is tack welded to the "V" and the upper flange slipped into place. Tack welds tie all units together. The body is then removed from the form and completely welded outside and inside. Following welding, the inner

welds are smoothed up by grinding. The flanges are surface ground and tested for leaks with 30-pounds air pressure in a water bath. This form method of construction was subsequently used for other odd shaped machine guards with the exception that hardwood forms were used.

The welded pocket possesses many features not to be found in the cast aluminum design. The weight is approximately 10 percent heavier than the aluminum design but as the movement is reasonably slow, inertia loads are negligible. Experience with the aluminum pockets on other machines showed it to be almost impossible to obtain sound castings. As these machines require a tight pocket for maximum testing efficiency, any porosity is detrimental to efficient operation. It is often necessary to peen the pockets to close "weepers". This entails endless testing of the pocket and actually increases the overall cost of assembly of the machine. In the welded design of pocket rolled steel being used in its construction, the only possible leaks are in the welded joints which show up immediately on the water test and leakers are easily corrected.

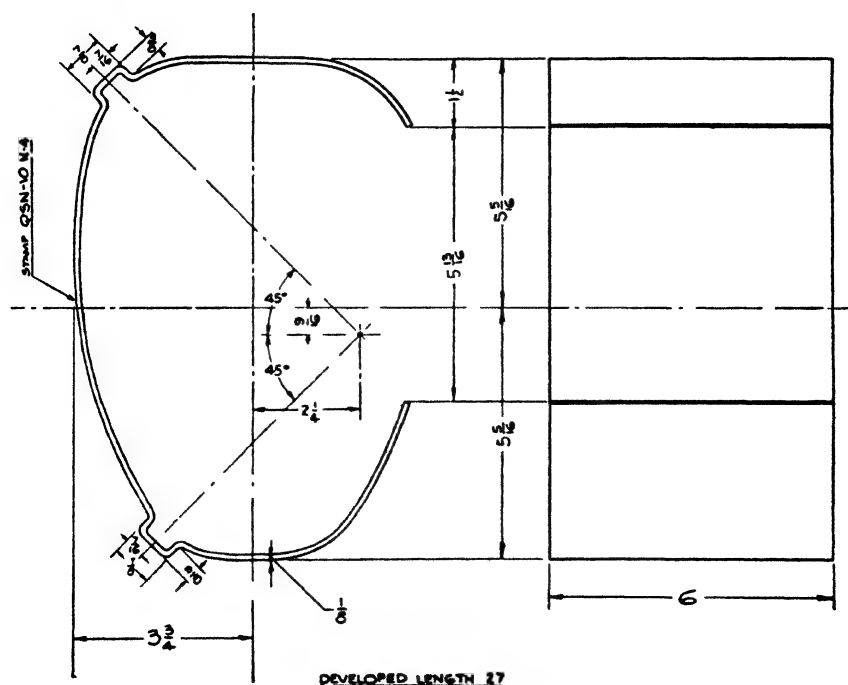



Fig. 5. Chamber wall.

Rigid company rules prevent the dissemination of any machine cost data. Therefore, only a few points of saving can be given. First, is a reduction in pattern cost amounting to a total of $1550. The machine weight was reduced 1800-pounds with a corresponding reduction in cost amounting to the differential in price of cast iron against rolled steel. The welded steel members in spite of their reduced weight, resist failure or breakage due to can jams. It can be stated at this point that can machine design presents a peculiar problem. Normally, the parts used to move a

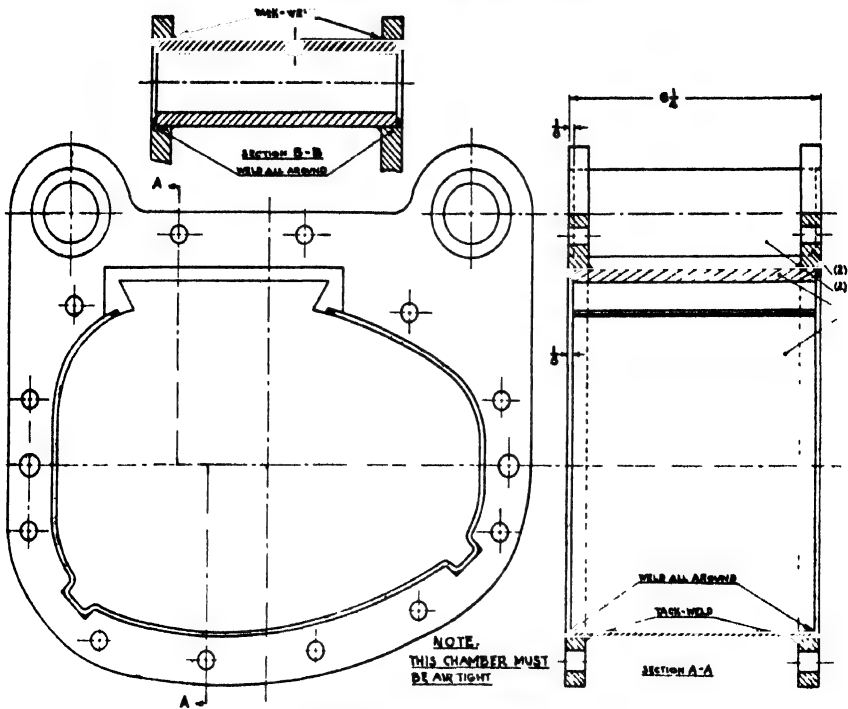



Fig. 6. Test chamber.

can weighing at most 1 pound, should be of light construction and this would be satisfactory if no jams would ever occur. When a jam does happen, due to some cause of obscure nature, the can handling parts must have the strength to resist the baling action of squashing a can. For this reason, steel members are preferred. The welded pockets on this machine saved over 100-hours machining time, to say nothing of the annoyances and time loss due to porous pockets as on the cast construction.

There is no doubt as to the value arc welding has given to our industry. It makes possible the construction of highly specialized machines at a cost low enough to permit early amortization.

Chapter XXXV—Redesign of Rayon Processing Machine

By Richard W. Stanley,

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Richard W. Stanley

Subject Matter: The processing of rayon yarn produced by the "box spinning" system requires a series of washing treatments. These treatments are mostly carried on in highly corrosive solutions which even stainless steel cannot resist. The original design used carriers assembled from castings which were suspended from a monorail conveyor system. Arc welded construction permitted a more compact design which moved the carriers through the process without the clumsy overhead conveyor system. The original design was unsatisfactory in operation and yet it cost 34% more than the better arc welded machine. The main saving, however, is the difference in maintenance cost. Each of the four new machines had about $22,512 less maintenance per year than the original design. In other words, arc welded design reduced maintenance cost from 10% to about 1% of the original machine cost.

In the process industries, the widespread adaptability of arc welding to the construction of tanks, pressure vessels and piping has established this method as an indispensable instrument of construction and progress. It follows quite naturally therefore, that the design of more specialized process equipment should be greatly enhanced from the start when the possibilities of welded construction are realized and taken advantage of. In this instance particularly, the opportunities offered in welded construction proved so numerous and clearly obvious that it would today be found both difficult and costly to design equivalent apparatus without the use of welding methods.

The subject to be described, a highly specialized processing machine for viscose rayon yarn, was designed as a direct result of the difficulties encountered in the performance of a full-scale pilot machine, the primary purpose of which was to serve not only as a production unit but as a final check as a design basis for the construction of four additional machines. This initial machine was placed in service in 1939 and, after 90 days of operation, the combined judgment of a group of engineers determined that a complete redesign would be necessary before attempting the construction of additional machines. At first glance, this drastic decision would appear as an indictment of the machine's designers for their apparent failure to anticipate the requirements with due thoroughness. Mildly so, this was true but when comparing the redesigned machine with the original, the conspicuous difference at once occurs as lying in the general approach to the whole problem.

In the case of the original design, almost anything excepting a straight length of angle iron or a plain piece of cold rolled shafting was designed as a casting simply because castings had always been used before, even way back in grandfather's time. This same attitude was reflected in other forms as well. Because a major portion of the machine took the form of mobile units, this major portion ended up by being hung from a monorail carried by a special superstructure. The monorail conveyor salesman won out in

this case. A manufacturer of silent chain recommended and sold 500 beautifully machined sprockets and 600-feet of double-back silent chain for driving 400 spindles of the machine at the speed of 10 revolutions per minute. These points are mentioned here to stress the one significant fact which dominates the efforts of still too many designers and engineers, that reluctance or sheer neglect to accept and make fullest use of the boundless opportunities to be found in welded construction. The very acceptance of these newer opportunities so widens the scope of the design possibilities that its effect automatically minimizes the other persuasive influences, for a free and open mind is an independent mind as well. Fortunately, the fast-moving pace of today's industry is establishing these facts solidly and those diminishing exponents of yesterday's methods will soon be extinct.

When the scope of this particular project is realized, each machine and its directly associated accessories representing a cost of more than $200,000, it is emphatically clear that nothing short of most modern design treatment and construction principles can insure the benefits to which such treatment entitles us. The truth of this statement is brought out in a comparison of both cost and performance records of the original machine with those of the completely redesigned machines, three of which have completed 1 year of continuous (160-hours per week) operation.

Purpose of Machine—To more readily understand the construction and operation of the machine to be described, a brief explanation of its functions and purpose is appropriate here. In the manufacture of continuous-filament viscose rayon yarn, three systems of spinning are in commercial use: the first, the box-spinning method; second, the bobbin-spinning method and, third, the continuous processing method. Predominating among these is the first, or box-spinning method under which system three-fourths of the world's production of this type of yarn is manufactured. Our subject concerns this method of yarn production.

The term "box-spinning" derives from the rotating cylindrical box or can in which the yarn is collected at the spinning machine, just following its
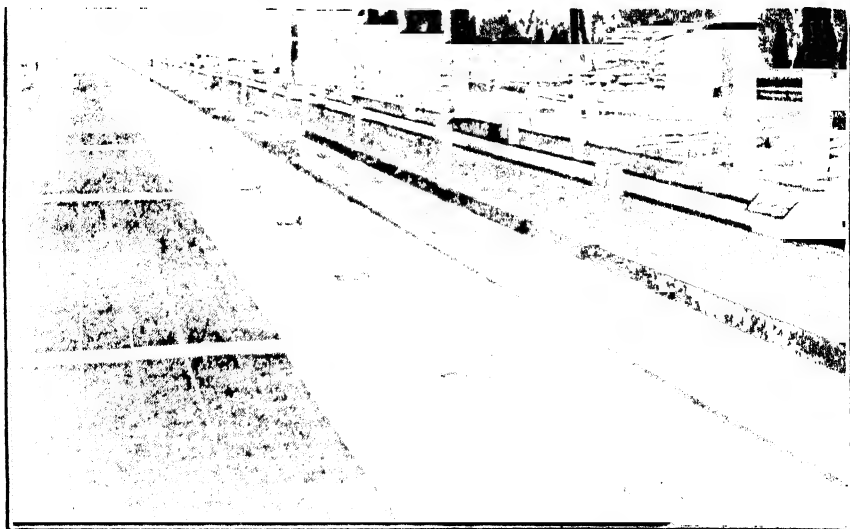
Fig. 1. The major welded structures.
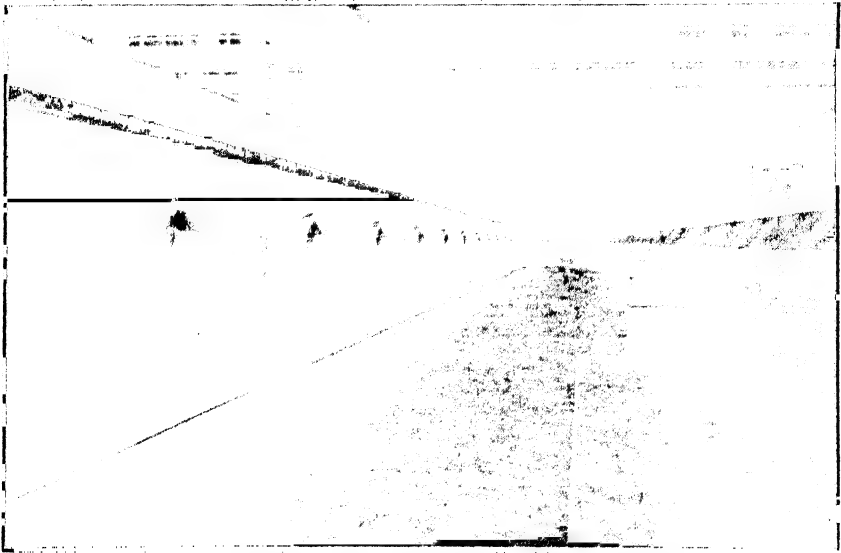
Fig. 2. Another view of the major welded structures.

chemical transition from a fluid state, through a sulphuric acid coagulating bath, to that of a continuous fiber. The yarn package thus formed is commonly termed a "cake" and its dimensions roughly, are 7-inches outside diameter, 4½-inches inside diameter and 6-inches in length. Such a package of average denier yarn contains approximately 36,000 yards. When leaving the spinning box the cake is thoroughly saturated with sulphuric acid which, after completing its action of "setting up" the freshly spun yarn, must be completely removed by a series of washing treatments. These treatments are progressively applied and consist in general of a further acid application, a desulphurizing wash, bleaching wash, several rinses and finally, a soft finishing liquid treatment. It is for these treatments that our subject provides and, while this machine has thus far been broadly termed a processing machine, it is more precisely known as a "cake washing" machine. The development of direct cake processing is one of recent years. In the 30 years of rayon manufacture in the United States, this development represents the most far-reaching production improvement yet made. Comparison of this newer method with those in former use is an interesting story in itself but further explanation here is unnecessary.

Machine Construction and Operation—In the ensuing description and discussion of the subject development, reference is made to the accompanying photographic illustrations. Figs. 1 to 4 inclusive are construction photos showing the major welded structures. Figs. 5 to 9 inclusive show the finished machine in operating form. Figs. 10, 11 and 12 show the machine as originally designed and are included for the sake of comparison.

This description, in the main, will treat the redesigned subject almost entirely with only occasional brief reference to its predecessor for making comparisons. The general machine dimensions are 250-feet length, 16-feet in width and three stories in height (including foundation pit). Approximate working floor space, including wood platforms is 5,000-square feet

(20- x 250-feet) as compared with the superseded design which, because of its single story design, requires a working floor space of 12,000-square feet. The backbone of the machine consists of 12 box-section base members each 20-feet in length and bolted together, end to end, to form one continuous machine base, 240-feet long overall. This composite base structure runs directly down the middle of the machine area at the approximate level of the working floor and is supported on adjustable jack screw mountings carried by suitable I-beams which are spaced at 20-foot intervals along the foundation pit, Fig. 8. Throughout the full length of this base structure and along its top surface is mounted a pair of steel rails for the support of a series of carriage units. These carriages, each 5 feet long, consist mainly of a box-section housing member, which is mounted on suitable roller-bearing wheels. Each carriage mounts a group of 9 rotatable spindles which extend from both sides of the unit. Attached to the spindle extensions are further extending members in the form of tubular arms which are made of stainless steel These arms are of a modified circular cross-section and, in their normal positions, present a flat portion as their uppermost surface. This flat portion is suitably perforated to permit passage of the various treating solutions to the inside of the yarn cakes. In Fig. 9, the actual cakes are shown. It will be observed that these wash arms are provided with a flange or disc members, welded to the arm near its inner end, while at the outer end, a removable flange member made of rubber, cooperates to close both ends of the "tube" formed by the group of yarn cakes and permits thereby the forced egress of the solutions through the cakes themselves.

A stainless steel distributing tank of welded design supplies each wash arm, through suitable connections, with the treating solutions. Such a tank
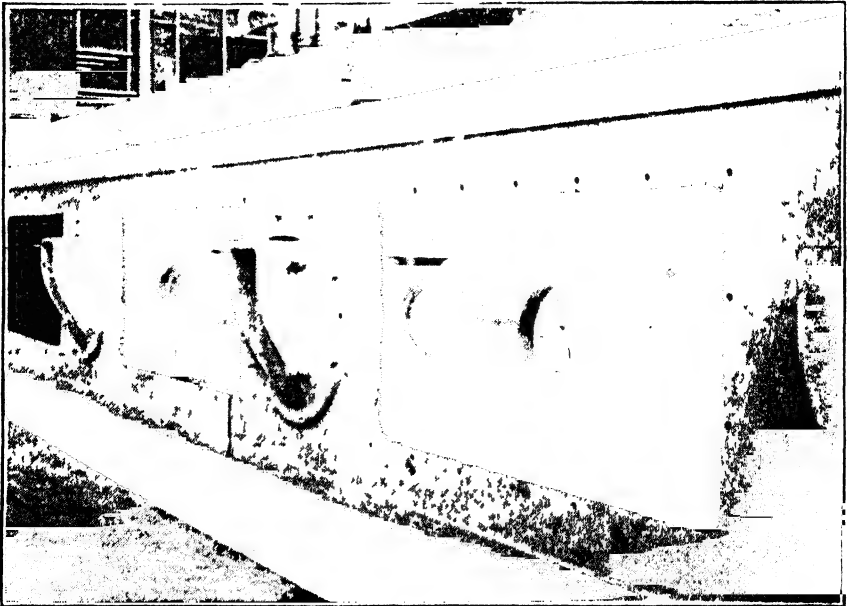
Fig. 3. Close-up.
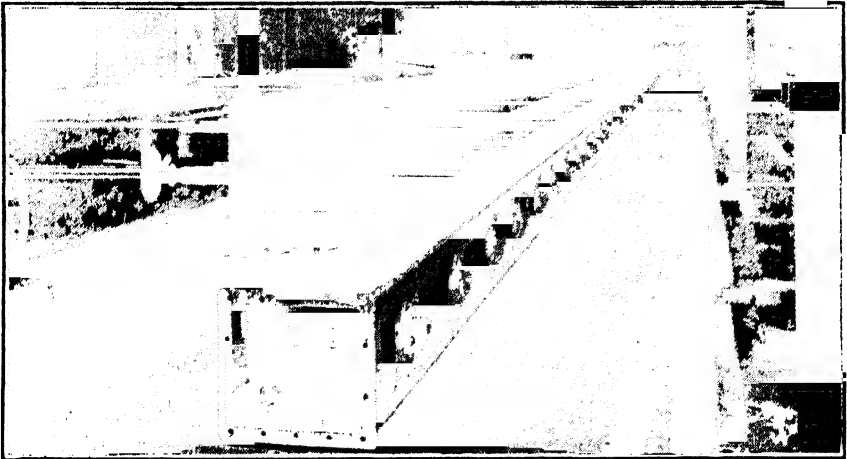
Fig. 4. Parts prior to erection.

is mounted on the top surface of each carriage unit Since the carriages are moved along their tracks at regular intervals of 3¼-minutes for the progressive treatment of the yarn through the various solutions, a flexible connection is required at each processing station This is accomplished by means of an inflatable rubber ring gasket formed like a doughnut and operated by compressed air

At this point in the description, it is important to mention two of the major reasons for the redesigned machine here described To begin with, the solutions used in the process are highly corrosive in their effect on practically all metals Stainless steel itself cannot resist the corrosive atmosphere and only by virtue of the final neutralizing wash which the yarn receives,
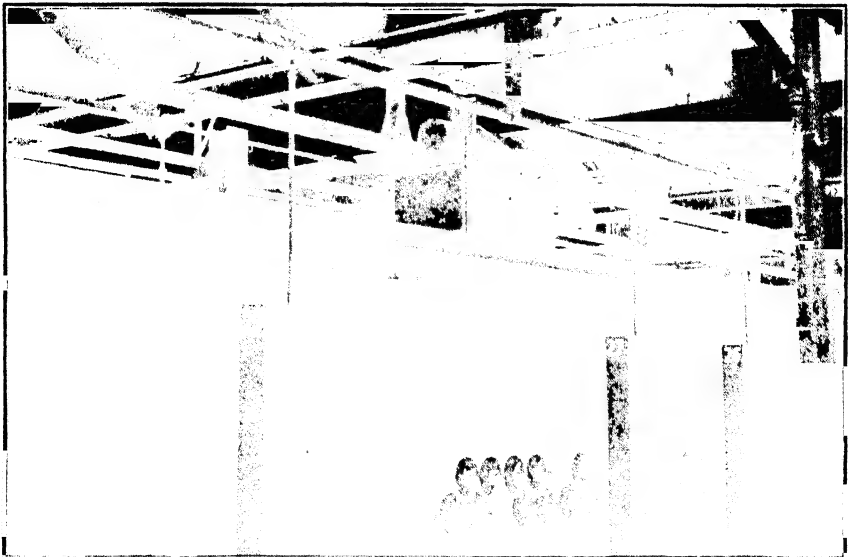
Fig. 5. Close-up of machine in operating form.

is its use permitted in the applications described. To combat this condition, all metal parts are coated with the best chemically resistant paints obtainable and in the case of the steel drip troughs which run along either side of the main base section these are treated with no less than six coats of a special synthetic resin finish which is baked on in electrically heated ovens. This process is naturally expensive and is restricted to those parts where nothing else will serve the purpose.

In the original machine, wherein the yarn carrying units were suspended from an overhead monorail and steel supporting structure, the solution catch basins were formed as permanent concrete vats resting directly on the floor. Many of these were lined with special acid-resisting tile and cement which gave reasonably good results. These vats, furthermore, extended across the full width of the machine. Therefore, not only the solutions directly below the wash rods were exposed to falling debris arising from corrosion and vibration of the overhead monorail structure and piping, but to that coming from the carriage units themselves. A vapor-exhaust system of canvas was used but an efficient design was made impossible because of the complex overhead structure. As a result, the installation of elaborate filters at once became necessary to prevent the carrying of foreign particles to the yarn which in itself is a very effective filtering means. These filters require careful and constant maintenance. No filters are required in the revised design. Therefore, in the construction of additional machines, all possible elimination of overhead mechanism was considered most important along with the provision of an adequate exhaust system of a simple and efficient design. This was attained in the first place by abandoning the monorail principle through supporting the carriage from below; dividing the catch basins and installing all piping underneath, and, providing a non-metallic exhaust hood (resin-bonded plywood with resin varnish treated surfaces) above the machine for substantially its entire length.

The second major weakness of the original design lay in the use of
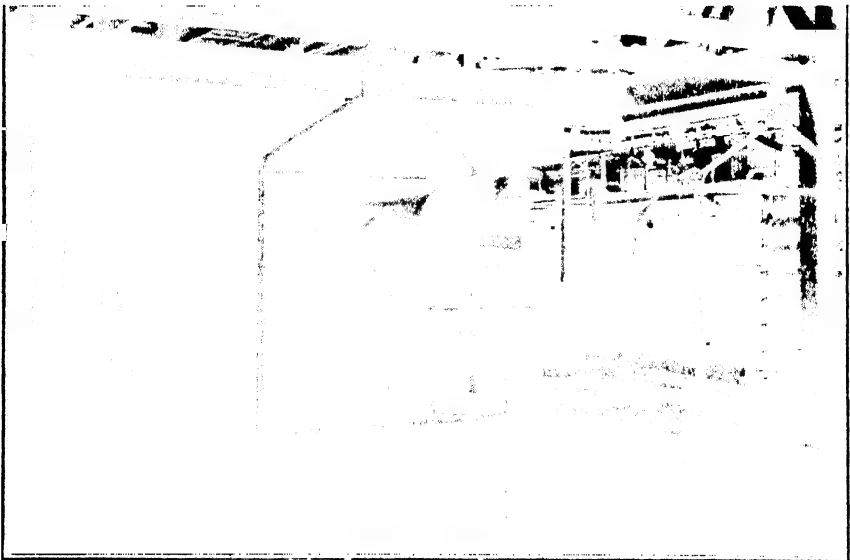
Fig. 6. Another operating view.
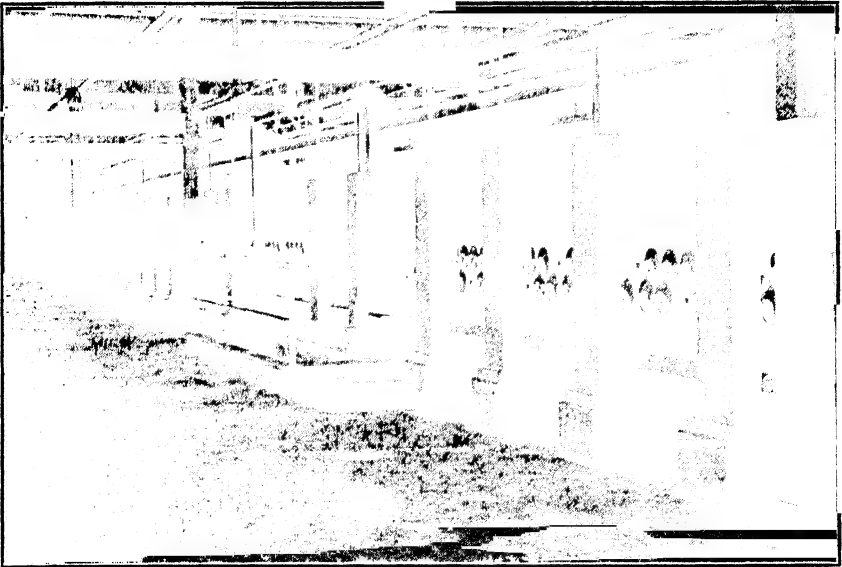
Fig. 7. Partial view along one side.

individual electric motor drives on each carriage unit for the purpose of rotating the wash arms. It should be explained here that for fullest effectiveness in processing the product, it is required to gently rotate the wash arms one revolution about once every 5 minutes. In other words, at 30 of the 48 processing stations throughout the machine's length, the wash arms are given a single rotation. At 15 stations, this rotation is clockwise in direction; at the other 15, counter-clockwise. In this instance the designer succumbed to the influence of the electric motor salesman who recommended a motor-driven gear reduction unit, complete with an enclosed magnetic brake. Unfortunately this design required a trolley wire system of exposed conductors carried by the monorail, which construction, because of its unavoidable exposure to corrosive vapors, requires constant maintenance. Switch parts too, because of their operation every $3\frac{1}{2}$-minutes, require frequent attention. This illustrates the second major requirement, that of a positive and efficient method of arm rotation. There was an interesting solution of this problem.

Each wash arm supporting spindle carried by the car unit is mounted in ball bearings and provided with a drive gear. These gears form a continuous train, spindle to spindle, and receive their motion through a pair of miter gears and a short vertical shaft entering through the carriage bottom. This vertical shaft is in turn driven from a second vertical shaft mounted in the base section and is coupled thereto by a specially designed "two-jaw and square block" type of coupling which permits automatic engagement and disengagement when the carriage moves along the machine base. The second vertical shaft in the base section is further provided with a gear which is adapted for suitable rotation by engagement with rack teeth which are machined in a tubular sleeve member. By means of a hydraulic cylinder, the tubular rack member is moved endwise for a distance equivalent to the circumference of its mating gear and the single revolution of the wash arms is thus effected in a simple and positive manner. An

additional mechanism is provided to shift the tubular rack member out of engagement with its mating gear, locking the latter against rotation while the former returns to its starting position.

Other mechanisms included in the base sections are the carriage advance motion for the simultaneous movement of all carriages in the train from station to station, and a plunger operating mechanism for locking each individual carriage in position when at rest. This latter device insures positive registry of the carriage units with the vertical shaft couplings and the solution delivering connections. The carriage advance mechanism comprises in general a series of vertically movable hollow plungers mounted in the base sections and adapted at their uppermost ends to carry a pair of rails formed by standard 6-inch channels, (See Fig. 1). This pair of rails runs the full length of the 240-foot base section, as shown. Along these rails at intervals of 5 feet arc welded steel castings of U-formation. When the vertical plungers are moved upward by means of the swinging action of a secondary pair of channel-shaped rails contained within the base sections, these U-members engage a suitable cross bar carried on the underside of each respective carriage unit. Thus, when the uppermost pair of rails is moved longitudinally through its connection with a hydraulic operating plunger, the entire train of carriages, 49 in all, is moved a distance of 5-feet. Then, as the rails recede downward, the carriage locking plungers mentioned earlier simultaneously engage the respective carriages and at the same instant, the pneumatically operated "doughnut" seals are inflated
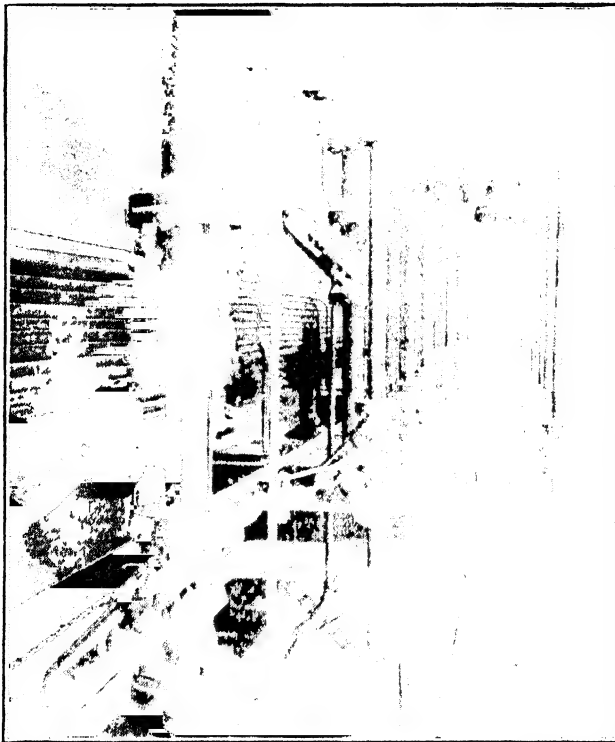
Fig. 8. View from foundation pit.

and the processing continues. This carriage advance motion, as well as all other phases in the cycle, repeats at 3½-minute intervals and after 48 such cycles, or a total of 2-hours 48-minutes, the first carriage load of raw yarn is discharged at the outfeed end, ready for the subsequent drying process.

To complete the description, it should be explained that at each end of the machine a hydraulic elevator, designed as a part of the machine, is positioned. Thus, after a carriage is unloaded at station 48, (See Fig. 9), it is transferred by means of the traverse rails just described, to the elevator directly in line with the unloading station 48. Directly following this transfer the elevator rises for a distance of 8-feet. At this point the carriage thereon automatically engages a strand of heavy roller chain which is confined within a welded steel supporting track running the full length of the machine. This chain is then set into motion through a hydraulic motor drive and the carriage is thus propelled to the infeed or loading end of the machine where it is received by a similar elevator, lowered to the operating level and again automatically transferred from this elevator to station No. 1 where it is loaded with raw yarn for another trip through the process. Support of the overhead carriage return rails is ideally provided for in the structural steel framework required normally for suspending the plywood exhaust duct described earlier. An excellent view of a returning carriage is shown in Fig. 5, while in Fig. 6, a carriage just lowered from the return track stands ready upon the elevator platform, for transfer to the loading station No. 1.

Before discussing the major welded subjects of the machine, namely the base sections and carriage units, attention is directed to the illustrations Figs. 1, 2, 3 and 4 which show these particular parts during the course of the machine erection. Fig. 7 shows a partial view along one side of the machine and displays in particular the welded steel instrument supporting columns opposite their respective processing stations as the numerals thereon indicate. Various pressure gauges, pump controls, indicating thermometers, etc. are attached to the inner faces of these columns. Fig. 8 is a view taken from the foundation pit below the machine in which the numerous pumps, supplementary tanks and valves are located. For several processing solutions, rubber-lined pipes and valves are used. Others require stainless steel and in these cases, many of the fittings, as the flanged tee shown in the foreground, were fabricated of light-welded tubing. All of the high-pressure hydraulic system tubing in ½-inch, 1-inch and 1¼-inch diameter are of the butt-welded type. Each machine uses over 4,000-feet of hydraulic tubing. Operating pressures range to 1,000-pounds per square inch. The entire machine cycle, incidentally, comprising thirteen separate but consecutive phases, is entirely automatic and all motions are hydraulically operated, receiving pressure from a single pump unit.

Welded Design Features—Of the various parts of this machine designed for welded construction, the base sections and carriage frames are the most interesting. Particularly so is the base section. It will be remembered that one of the principal objectives in the new design was a maximum degree of protection of the machine parts, particularly those surfaces subject to wear and hence, incapable of surface protection as by painting. Total enclosure of such parts plus adequate lubrication provision is one safe method to follow. The first approach toward this end began with the provision of baffle plates attached to either side of each carriage unit. By this means, occasional splashes of processing solutions coming from the wash arms or catch basins would, at their worst strike the baffle plate and then drip off
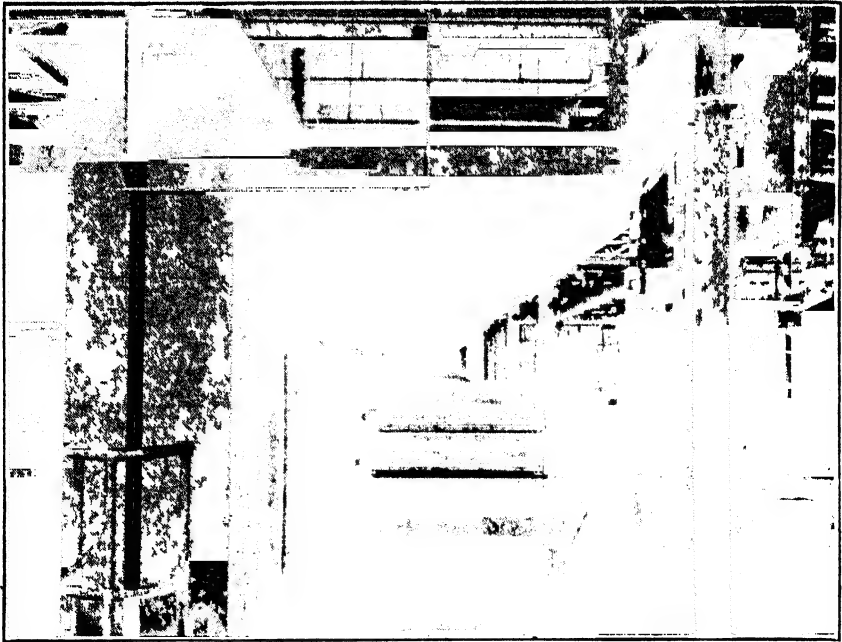
Fig. 9. Unloading station.

its lower edge to the basement below where no particular harm would ensue Thus, the carriage housing itself is protected as well as the base mechanism

It was, furthermore, desired that the mechanical design should permit an occasional application of water from a hose directed against the baffle plates This explains the careful provision of oil seals and other baffle features For the various mechanisms involved no construction could afford better protection than a box design This is precisely the form which the base sections, as well as the carriage housings, take An individual base section is a box section having machined dimensions of 30-inches x 33½-inches x 20-feet long In proportion to its somewhat unusual length as a machined part and the numerous purposes it serves, the cost of fabricating this member was surprisingly low While being a four-sided box it was fabricated of only two plate members, excluding of course, the "picture-frame" end flanges and two center ribs These two plate members, ⅞-inch thick as rolled, were bent to form U shaped channels 32¼ inches between the legs and approximately 14½ inches deep The edges were then prepared for an abutting V shaped weld and the two channels then welded together to form the box section The weld thus made occurred along the horizontal neutral axis of the section and, since large portions of the vertical walls were afterwards cut away to provide the rectangular and circular openings shown, welding of the joint through those cutaway areas was not required As a welding project, only the end flanges and center frames remained to complete the job The most exacting phase of the fabrication lay in the accurate formation of the channel shapes and a careful welding procedure to insure the degree of accuracy required for finishing to the given dimensions To the commercial welding fabricator this subject presented no unusual problem and a quantity of 48 base sections was fabricated and machined without incident
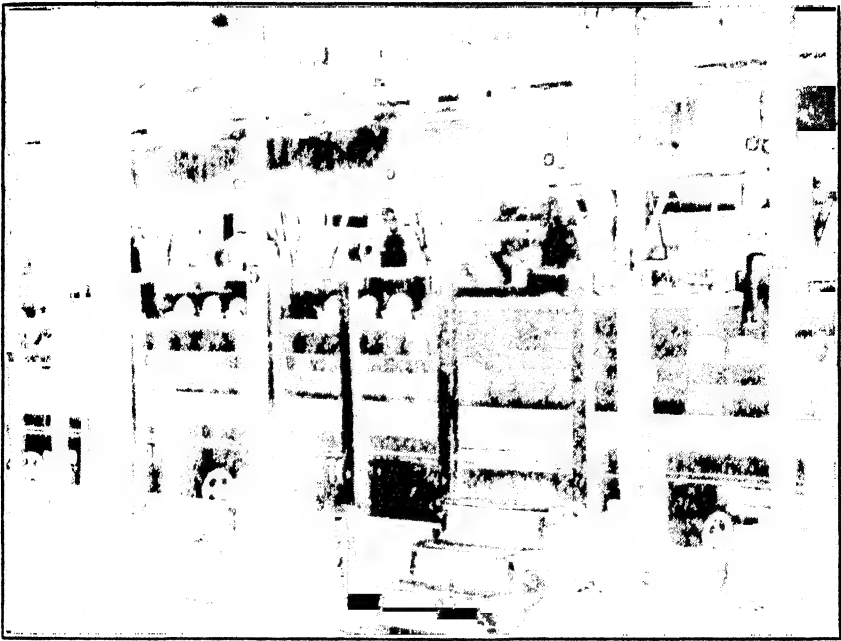
Fig. 10. Carriage unit, original machine.

The question of machining these base sections was carefully considered. On all four sides, numerous machined parts are fastened If this base were a cast part—and it is barely conceivable that a steel casting of such a comparatively light cross section could be made to such a length--the numerous finished surfaces would be formed as raised pads In this member there are 28 large bored openings and 10 rectangular ones, all of which require machine-finished margins for the sake of accuracy and tightness In this case it developed that the preparation of 38 individual pads and their attachment to the main member would be far more costly than to machine the four sides as continuous surfaces These long straight surfaces were of additional value in the erection of the machine

In the case of the carriage frames, advantage was taken of bending when possible, to form the corners Beyond this, the procedure was one of straightforward welding with only the necessary care to insure the required degree of accuracy and squareness to provide the necessary allowances for machining As in the case of the base sections, these housings were completely stress relieved before the machining operations No machining pads for the bored openings in the sides were necessary since spot facing of a limited area around each opening provided sufficient accuracy For the 9-inch diameter hole in the underside, a raised pad was welded on to permit using a ¼-inch plate for the bottom wall Here, a separate pad was the better design

Arc welding was extensively used in the construction of the V-shaped drip troughs which lie along both sides of the machine 12 circular tanks located in the foundation pit beneath the machine were of arc welded steel construction The platforms and bases of the hydraulic elevators were of welded design The 5-foot stroke carriage advance cylinders (two

per machine) combined a seamless steel tube with cast steel ends and center supports by welding.

The overhead steel structure for supporting the exhaust ductwork and the carriage return rails was erected with temporary bolts and then field welded in place.

The distributing tanks on each carriage were formed of 14-gauge stainless steel. Each tank is formed with a dished head in one end and a removable dished head, for inspection purposes, in the other. T-shaped tubular take-off connections are welded into the tank bottom for connecting with the wash arms by rubber tubing. Tank support saddles are of light plate and angle construction. See Figs. 5 and 6.

Comparison of Welded Design Versus Original Design—For a comprehensive comparison of the subject machine with the original, this is best had by dividing the discussion into three phases, viz. :

1), Actual saving in initial cost for equivalent apparatus fabricated by arc welding over that produced by the previous method;

2), Actual total annual savings accruing as the result of improvements obtained through arc welded construction;

3), Improved service life, operation and quality of product resulting from the use of arc welded design.

In both the original and redesigned machine, the extensive use of stainless steels, special acid-resisting pumps, valves, piping, etc. resulted in a high initial investment irrespective of the type of machine construction used. For determining the effect of arc welded design on the initial cost according to factor No. 1 noted above, a direct comparison will be made between the cost of the welded items and the cost of original items directly replaced thereby. The figures given are accurate, having been obtained from actual
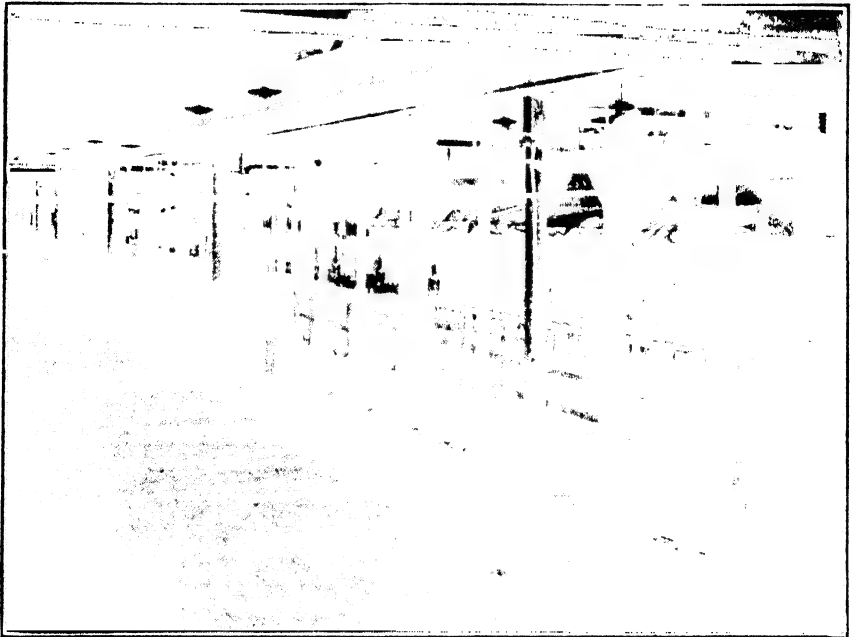
Fig. 11. Another view of the carriage units, original machine.

records. The welded construction costs have been modified to represent those of a single machine project since the redesigned subject as described was ordered in a quantity of 4 complete machines.

Carriage Units—Original Machine—Figs. 10, 11 and 12.

These units consisted of cast aluminum housings for enclosing the wash arm spindle mechanism. A steel framework of partially welded angle construction was included for suspending the spindle housing from the monorail carrier system. The figure given is our purchase price of these items only, fully machined and ready for assembly,—

53 Units @ $347. each..$18,391.

Carriage Units—New Machine—The following figure is based on the welded and machined carriage housing, steel cover plates and baffle plates which compare in function with above items. This is the purchase price for these items,—

53 Units @ $176. each..$9,328.

Monorail System—Original Machine—That portion of the monorail carriage supporting system including its supporting structure and considered as directly comparable with the functions of the new design base sections as carriage supports is here represented only..............................$8,740.

Base Section Members—New Machine—The following cost figure represents 12 base sections fabricated and machined. The carriage support rails are also included. Inasmuch as these members serve in numerous additional capacities, it is considered a fair comparison to give this figure so qualified.

12—Base section units with rails @ $710. each..............$8,520.

Totalling the above gives the following:

Cost as originally designed..$27,131.

Cost as redesigned for
Welded Construction ....$17,848.

Net difference in favor of
Welded Construction ....$9,283.

or, an initial saving of 34 percent over the original design.

In the case of the stainless steel carriage-mounted solution tanks, those of the new design incorporated several additional features over the first design. In the original case, these tanks were formed as open catch boxes for receiving the solutions from overhead delivery pipes. The resulting processing pressure was therefore limited to the equivalent head of about 42-inches which the design provided. In the new machine, the tanks were designed to operate as part of a closed system to permit higher processing pressures and a proportionate increase in the processing rate. Hence, no cost comparison with the previous construction can be fairly made.

More striking economies appear in the annual repair and maintenance records of both the original design and the new machine. In determining these figures, lubrication expense is not included. While probably not all of the difference between the following figures can be directly and solely attributed to the use of arc welded design as indicated in Factor No. 2, it is a definite fact that the new design features permitting the improved economy in maintenance resulted directly from the choice of welded construction.

Repair and Maintenance Expense of the original machine for the first 12 months of operation..$25,262.

Repair and Maintenance Expense of the arc welded machine for the first 12 months of operation..$2,750.

Net Difference in Favor of Welded Construction..........................$22,512.

or a saving of 89 percent in these charges.

Fig. 12. Another view of the carriage units, original machine.

In proportion to the total initial cost of either machine which in both cases was approximately $250,000, the first repair and maintenance figure is better than 10 per cent, a thoroughly prohibitive amount. In the case of the new design the repair and maintenance figure is slightly over 1 percent.

The one most significant fact which stands out above all others is the tremendous latitude at once available when the possibilities lying in arc welded construction are realized. This project illustrates the point so clearly. In either case, the specifications to be met were the same. The drastic difference between the first and second designs is directly traceable to the individual's approach to the problem. The first design was developed by a methodical and generally reliable type of individual but who otherwise relied almost entirely on precedent, looking forever backward for something done before. The second design was approached as just another opportunity for further progress and with the serious purpose of investing the company's machine dollars in the best form of equipment obtainable

In the design of chemical process equipment particularly, the factor of service life is most important as well as utmost reliability to insure continuous uninterrupted performance. From the results thus far, the service life for the redesigned equipment should be increased many fold over that of the previous design. Repair and maintenance becomes almost a negligible factor and the operation throughout the life of the equipment, a matter of assurance instead of an ever-doubtful one.

Chapter XXXVI—Welded Lining of Horizontal Processing Tanks

By W. E. SHEFELTON

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W. E. Shefelton

Subject Matter: Three large tanks, which were made from flange-quality steel, eight feet in diameter and 30 feet long, were badly corroded in a rayon plant. A temporary small slot, three inches wide and 50-inches long, was cut in each of the tanks to admit the preformed 16-gauge stainless steel sheets. Since the old flange steel shell had a different expansion rate than the new stainless lining, it was necessary to insert expansion joints in the new lining. These joints were small channels bent on a brake and later rolled into a hoop to cover the joints between sheets. No corrosion has been found after 2-years' service. This method of repair saved $27,934.61 over replacing the corroded tanks with clad-metal new tanks. Additional data is given on savings in the dyeing vats for textile plants and special tanks for processing foods.

This paper deals with the lining of parts of three horizontal processing tanks in the rayon industry. The lining being applied only to the part of the tanks where corrosion of the tank shell was taking place.

The tanks, as originally built, were A.S.M.E. pressure vessels, 8-feet diameter x 30-feet long, made of ½-inch thick flange-quality steel. They are for the recovery of acetate used in one of the several processes for making rayon. Each tank as originally built contained a stainless steel basket for holding carbon, together with gutters to catch the condensate from the top part of the tank and carry it away without allowing it to pass into the carbon. The carbon serving to separate the acetate vapors from other vapors and gases. When these tanks were originally built, there was some discussion as to whether the flange quality steel would stand the corrosive effect of the process. It was decided that the flange quality steel would be satisfactory, so the tanks were built as per dotted lines on drawing. The basket, diffuser nozzle, diffuser and condensate gutters were made of 18-8-SMO type 316 stainless steel.

In a short time after the tanks were put into service, it became evident that the acetate vapors were attacking and dissolving the flange quality plate above the carbon basket and deposits of the dissolved steel were forming where the condensate gutters joined the shell. In some places there were pieces of this deposit weighing as much as 10-pounds and resembling coral formations.

This condition was allowed to exist for a time until the tanks started leaking, and the insurance company insisted that the tanks be repaired or replaced to meet their safety requirements. Acetate vapor leaking from these vessels might cause a serious explosion. My company's principal business is special steel plate construction and their representatives were called in to make recommendations on rebuilding these tanks, if possible, to keep them in service and save the expense of removing and replacing them.

The writer made a preliminary inspection of these tanks and noted that the flange quality plate was badly corroded, but the type 316 stainless steel in the

troughs and carbon baskets had not been affected. We recommended lining the top part of these tanks where corrosion existed with the same type of stainless steel of which the gutters and baskets were made.

The owners considered several propositions, other than lining the tanks with stainless alloys, such as using a new rubber product which would withstand the acetate vapors at regular temperature, but which the manufacturer would not guarantee at the temperature it was necessary to use in steaming out the carbon baskets. Another product considered was a synthetic resin coating. Samples of various materials were tested inside the absorber tanks, but were not satisfactory.

The problem of lining the tanks with stainless steel was to make the lining vapor tight and keep the acetate vapors from the flange-quality steel. Also, withstand the changes in temperature which were necessary in the process. The process entailed the change from atmospheric temperature to approximately 250 degrees several times per day as cycles of the reclaiming process were carried out. The co-efficiency of expansion on stainless steel being much higher than the flange quality steel shell (about twice as great).

To take care of the expansion and contraction, it was decided to use some type of expansion joint at each seam. A small channel shaped section made of 11-gauge stainless strips bent on a plate brake was decided upon, (See Fig. 1, detail "B"). These channels being ½-inch deep and 1½-inches wide would serve to stiffen the lining, as well as take care of expansion and contraction.

The lining was prepared in the shop, as far as practical. Each sheet was cut to size and formed to fit the tank at the point it was to be placed. Those fitting the cylindrical part of the shell were cut accurately to size, rolled to the correct radius and bent where they entered the gutter in a plate brake, (detail "H"). The gutters were sloped for drainage purposes, to one end where the condensate was drawn off. This necessitated each plate which fit in the cylindrical part of the tank being slightly different from any other. The 12-gauge stainless sheets which were to line the heads were cut to shape, then dished and flanged. The linings for the various openings were prepared as shown on the drawing so that they could be installed in the field with a minimum of time and expense.

The channels were formed on a plate brake and where they fit on the cylindrical shell were curved to the proper radius on a plate roll.

After shop fabrication of the linings, they together with the necessary tools were trucked to the tank site ready for installation. Two 400-ampere welding machines and ⅛-inch rods were used for the welding. The welding machines immediately available were over-sized, but worked satisfactorily without any resistance being installed in the welding circuit. The machines were used with stainless electrodes to do all cutting in the field, such as holes for the nozzles in the linings and any place where it was necessary to cut the linings in the field.

The granulated carbon in the basket of each tank was valued at approximately $10,000. There would be some damage to it from foreign materials falling into it, if it were left in the basket while the work was going on. Reactivating it was desirable, therefore, this carbon was removed from one tank at a time and reactivated while the tank was being lined. As soon as No. 1 tank was finished and put into service, the carbon was removed from No. 2 and reactivated and put into service, and then No. 3 tank was emptied. By doing this, it was possible to keep the reclaiming process in operation all the time.

Fig. 1. Details of the stainless steel absorber tank lining.

The diffuser nozzle on each tank was connected to a 24-inch stainless steel pipe line through a 24-inch gate valve. This pipe line had been built with the tanks in place, and it would have been practically impossible to have set a new tank in position and connected without refabricating a part of this stainless steel line, which would add to the cost of installing new equipment.

The inside of each tank was thoroughly cleaned before the lining job was started. This cleaning being done with pneumatic hammers and power driven wire cup brushes. The diffuser which was made of perforated stainless steel sheets was disconnected from the nozzle and moved about in the tank as necessary to keep it out of the way of the workmen.

A slot about 3-inches wide and 50-inches long was cut in the shell of the tank and all stainless sheet materials required for the lining of the job were placed inside of the tank through this slot. The slot was then closed by welding, (See Fig. 1, detail "J"). All the pipe connections were opened to allow a good circulation of air. The workmen entered and left the tank through the 18-inch manhole on top. A 14-inch exhaust fan was placed in this manhole for forced ventilation at all times when there was any welding going on inside the tank. 16-gauge stainless steel was selected for the main part of the lining. The original steel shell was still in good enough condition to support this lining at the pressure required to carry on the process. Across the ends where the lining could not be as well supported, 12-gauge stainless sheets were used. The steel tanks varied slightly in dimensions, so it was decided to leave approximately ½-inch between all stainless sheets in this space to be varied to suit each tank. The 11-gauge stainless steel channels were then placed over these openings.

Work was started on the end of the tank at the diffuser. The end rings of two 16-gauge sheets were put in place and forced tight against the shell of the tank, using circle boards cut to the radius of the tank, with a piece of rubber hose on them next to the stainless steel to take care of any irregularities in the shell of the tank. These sheets were tacked into position to the original shell very lightly. Then the four end pieces were put in position around the diffuser nozzle.

In view of the fact that the location of these nozzles varied slightly, an additional ring of stainless steel was placed around the nozzle to save time in fitting. The four main plates being fitted to the head and shell of the tank, and the extra ring fitted to the stainless nozzle lining and then welded to the four main- plates.

Material required for 3 linings, Type 316 Stainless Steel

Item	Size		Weight		Price		Amount
21—Sheets, 16 Ga.	49 × 67½	=	1247#	@	$.5442	=	$ 678.62
24—Sheets, 16 Ga.	49 × 66	=	1419#	@	$.5442	=	772.22
1—Sheets, 16 Ga.	31 × 52	=	28#	@	$66.42	=	18.60
1—Sheets, 16 Ga.	36 × 62	=	40#	@	$66.42	=	26.57
1—Sheets, 16 Ga.	28 × 68	=	34#	@	$65.92	=	22.41
3—Sheets, 12 Ga.	42 × 61	=	241#	@	$.5992	=	144.41
3—Sheets, 12 Ga.	42 × 92½	=	363#	@	$.5692	=	206.62
50—Strips, 11 Ga.	2¼ × 96	=	280#	@	$.5942	=	225.80
Welding Rod			150#	@	$1.05	=	157.50
Boxing Sheets and Strips by Steel Mill for shipment to us.							35.72
Trucking tools and lining to job and tools back to plant							40.00
Net cost of material and freight							**$2328.47**
Profit on material							**232.85**
Selling price of material and freight							**$2561.32**

Shop Fabrication of Linings

Direct labor	$148.55
Overhead on above	222.83
Selling price on shop fabricating of linings	$ 371.38

Field Installation of Linings

124 Hrs. foreman	$191.00
480 Hrs. mechanic	600.00
	791.00
Overhead charged on above	566.30
Selling price field installation	$1357.30
Selling price on linings	$4290.00

Replacing tanks with stainless clad steel, $\frac{5}{16}$-inch thick:—This being the minimum thickness which could have been used. Due to size extras, it is more economical to use small plates about 5-feet by 12-feet, than it is to use larger plates. All stainless material, Type 316.

37—Plates $\frac{5}{16} \times 60 \times 152\frac{1}{2}$	= 31,000#	@ $.3250 =	$10,075.00
12—Plates $\frac{3}{8} \times 57 \times 114$	= 9300#	@ $.3050 =	2,836.50
1150—Sq. ft. 14-Ga. Plate	= 4000#	@ $.654 =	2,616.00
900—Sq. ft. Stainless Steel Screen		@ $3.00 =	2,700.00
1200—Lin. ft. 2 × ¼ Bar	2040#	@ $.565 =	1,152.60
600—Lbs. Stainless Welding Rods			630.00
600—Lbs. Electrodes			45.00
Freight to destination			240.00
			$20,295.10
Profit			2,029.51
Total selling price material and freight			$22,324.61

Shop fabrication of clad tank and basket, estimated for 3 tanks

3000 Hrs. @ $1.00 =	$3000.00	
Overhead on above =	$4500 00	$7,500.00
Field removing old tanks and installing new ones	$1500.00	
Cutting up old ones for scrap	200.00	
Overhead on above	1200.00	
	$2900.00	$2,900.00
Selling price 3 Stainless Clad Tanks		$32,724.61

Estimated selling price of 3 new tanks and baskets of Type 316 stainless-clad shell. Solid stainless basket, perforated with 2 x ¼ reinforcing bars, lined with 20 x 20 mesh stainless screen.

Less scrap value of original tanks after being cut up for scrap.... 500.00

$33,224.61

Selling price of 3 new tanks,)
less scrap value of old tanks)..........$33,224.61
Selling price of linings.......... 4,290.00

Savings effected by the Rayon Plant in having).......... $28,934.61
the tanks lined instead of replacing them.)
The lining cost 13.31% of the cost of the new tanks,
effecting a saving of 86.69%, over stainless clad tanks.

Tanks of solid stainless would have cost..........$13,300.00
more than the stainless-clad tanks, due to increased cost of material.

The lining cost 10.40% of solid stainless tanks or saving of.......... 41,234.61

The cost of material shown for the lining job was taken from our cost records and invoiced to customer.

The estimated cost for the new clad vessels is an authentic estimate. 12—5/16-inch plate for each shell and 4—3/8-inch plates for the 2 heads. The 37th 5/16-inch plate would be for nozzles.

Without welding, it would have been impossible to have done the lining job—in fact, it would be impossible to do the clad job. To replace the tanks without welding, it would be necessary to use solid stainless or ordinary steel. The first would have increased the cost $13,300, and the ordinary steel would have to be replaced every year or so.

The linings have now been in service for 2 years and show no sign of failure or corrosion, which is good evidence as to their lasting qualities.

The company with which I am connected specializes in steel plate fabrication, selling around a million dollars worth of various kinds of containers and processing equipment each year. They save on the average of 15 per cent of the total sales by use of arc welding, making a gross saving of $150,000 per year. Some jobs show a much greater saving than 15 per cent.

In addition to the saving effected by arc welding, we are able to manufacture some products at a cost which permits them to be sold to customers at a price they can afford to pay. This is especially true where clad metals or lining jobs are used in the textile, chemical or food industry.

Corrosion often can be eliminated so that the life of equipment is materially lengthened by the use of very thin layers of non-corrosive material. In other cases, the picking up of foreign substances from containers or processing equipment which discolors or causes the chemical or food to lose desired characteristics, can be eliminated. Up until arc welding became prevalent, this was impractical in most cases and impossible in many cases. The public, as well as the manufacturer benefits from the use of arc welding by securing many products at a lower cost, and also arc welding makes it possible to have many products we could not have before, because it has made possible the use of many alloys which were not practical to use before.

The writer talked with the superintendent of a rather large mill which had installed several hundred thousand dollars worth of non-corrosive alloy in his dye house. The equipment had been in use 3 years. I was assured that this equipment had paid for itself in less than the 3 years and was still in excellent condition. Before the use of arc welding, it was impossible to use such equipment.

The use of non-corrosive alloys in the dye industries has permitted a much wider variation in colors than was possible with cast iron and wooden dye vats, because the dye does not pick up any foreign material from the non-corrosive alloys. These foreign materials formerly made it impossible to cover

such a wide range of colors, as the foreign material picked up affected the color. The ease of cleaning non-corrosive alloy containers between batches as compared to the cleaning of corrosive containers in the case of dyeing equipment, sizing equipment, etc. saves much time in the textile industry.

A part of all savings such as has been listed is passed on to the ultimate consumer of the textile goods, and in this way civilization as a whole benefits from the use of arc welding.

Davison's "Textile Catalogue" lists:

2435 Cotton Mills; 942 Woolen and Worsted Mills; 153 Carpet and Rug Mills; 1101 Rayon and Silk Mills; 2357 Knitting Mills; 130 Commission Throwsters; 161 Jute, Linen, Flax, Sisal and Hemp Mills; 717 Dyers and Finishers; 123 Sanforizers.

The above makes a total of 8,119 textile plants in this country.

On a single job in one of these mills we have shown a net saving of $27,934. This is only one job of several we have done for this particular company on which we have been able to effect a large saving. If each of the 8,119 textile plants save but $2,000 a year, there would be a saving of $16,238,000 per year to the textile industry.

Our experience indicates that a considerable greater saving than this could be effected by the proper use of arc welding. The chemical and food industries have even greater possibilities of saving than the textile industries, due to the fact that a larger percentage of their processing equipment is subject to corrosion.

By the proper use of linings, such as described in this paper, it is possible in many cases to lengthen the life of equipment from a few months to several years, thus saving the owners considerable trouble, as well as expense.

Summary:

This paper	shows a saving of 86 69% against a clad job.	or	$28,934.61
This paper	shows a saving of 89.60% against a solid stainless job, which would be the only substitute possible, if it were not for welding.	or	$41,234.61
This paper	shows a saving by my company per year by the use of arc welding.	of	$150,000.00
This paper	shows a minimum saving	of	$16,238,000.00

to the textile and clothing industry by the proper use of arc welding.

This paper shows that by the proper use of arc welding the service life of certain equipment can be increased several fold. That the public as well as the manufacturer benefits by the use of arc welding.

Chapter XXXVII—Arc Welding in Press Machinery

By Lloyd A. Whittaker

Chief Engineer, Thomson National Press Co., Franklin, Mass.

Lloyd A. Whittaker

Subject Matter: This company had been making their machine frame from steel castings and plate with great satisfaction and economy. Steel plate priorities made it impossible to continue this method of fabrication and patterns were built for a cast iron frame. The weight was increased 500-pounds when cast iron was substituted and the strength factor is still doubtful in one highly stressed section of the frame Cost was increased from $157.62 per welded frame to $214 30 for the cast frame. There is no doubt in this company's mind whether they should return to welding when steel is again available.

A good many months before Pearl Harbor and shortly after this country started its national defense effort, machine manufacturers were informed that they would have to have priorities to secure the various types and thicknesses of steel which had always been taken more or less for granted.

The average company didn't take the possibility of rationing too seriously nor did we, who, at that time, were making a press to automatically cut, crease or emboss boxes, book covers, jig saw puzzles, etc. and for which the frame was being fabricated of steel, until it became quite apparent that we would not be able to obtain any more of these frames.

We intended to continue making these presses, if at all possible, since we had the feeder mechanism for several on hand and so had no alternative but to have pattern and core boxes made to use a frame of cast iron.

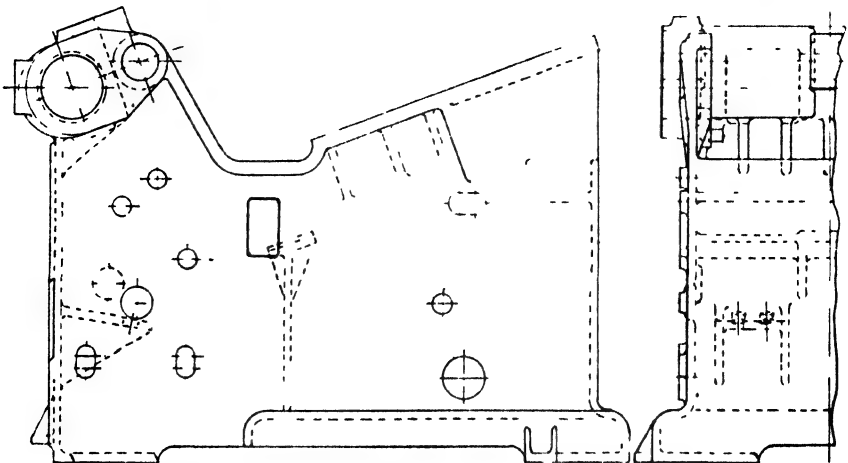



Fig. 1. Right-hand side view, cast iron construction.

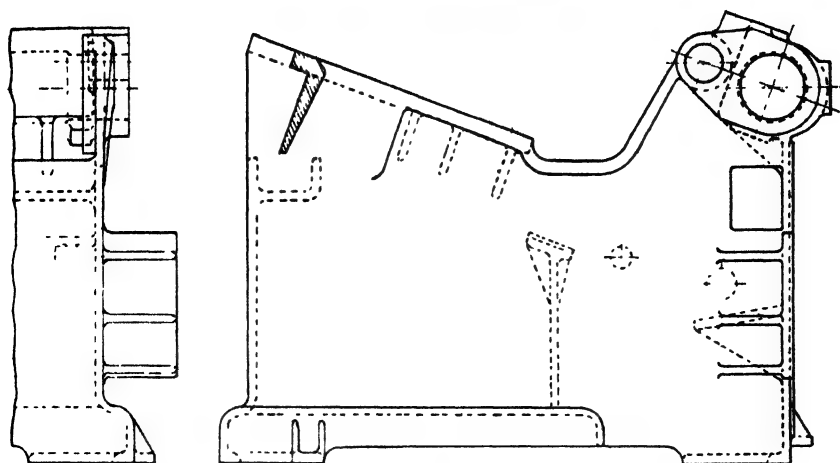



Fig. 2. Left-hand side view, cast iron construction.

The use of cast iron made it necessary to make the sections much heavier than had been the case of the steel frames and also to rib overhanging sections, and because of space limitations it was necessary to redesign the press.

Curiously enough this procedure was the reverse of the policy which we have followed for years inasmuch as cast iron frames had always been standard with all our machines, and a departure to a steel frame was made only when a press had to be extremely rigid or when weight limitations had been specified.

Figs. 1, 2, 3 and 4 show the right hand-side view, left hand-side view, front and rear views and plan view, respectively, of the cast iron frame.

A study of these views and also the section view of the head on Fig. 12 will suffice to realize that an extremely complicated system of coring is necessary to produce such a casting.

Figs. 5, 6, 7 and 8 show views of the same frame, drawn to conform to the redesign, made of welded steel and are in the order of right-hand side view, left-hand side view, front and rear views and plan view, respectively.

It will be observed on these four drawings that each separate part of the frame has been given a segment number which if shown on more than one view is the corresponding part and this numbering of the segments should serve to clarify the views.

Figs. 9, 10, 11 and 12 correspond to the previous four views but are broken up to show the individual segments and to show the method of welding and also the method of assembly.

Segment 1, the head, on Figs. 5 and 9 is a steel casting and is cast closely enough to require only torch cutting the radius to which the front and side frames are welded, and also torch cut the bevel for welding.

Segments 2 and 19, the side frames, are cut to size and shape with the holes cut out and the bosses welded into position while the frames are lying horizontal before assembly to the head. In this manner, the side frames and front and rear segments are made complete then welded together before the head is welded on, which is the last operation.

Fig. 13 is a sheet showing each segment in the quantity used, and the individual weights and the numbers of the segments will be found to correspond to those of the eight previous figures.

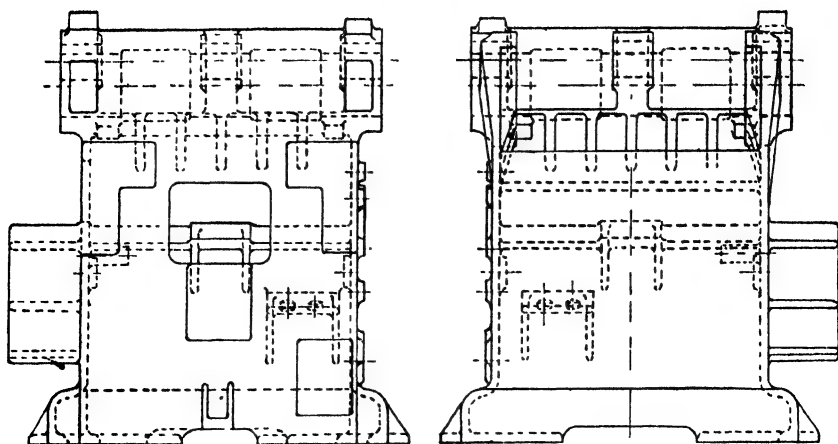



Fig. 3. Front (left) and rear views, cast iron construction.

The following tabulations will give the cost of the frame as closely as can be estimated, and these figures are based on comparatively recent figures of local suppliers of oxygen, acetylne and steel, also leading manufacturers of welding rods and equipment. Figures on labor and also electric power costs are based on conditions locally.

Due to the war effort and constantly increasing labor and material costs, these figures would not apply at the moment even if we could procure the material; however, the costs would increase or decrease proportionately between the cast iron frames and those of welded construction.

Labor ....$ .75 per hour
Overhead ....$ .75 per hour
Oxygen ....$1.40 per 100 cu. ft.
Acetylene ....$2.80 per 100 cu. ft.

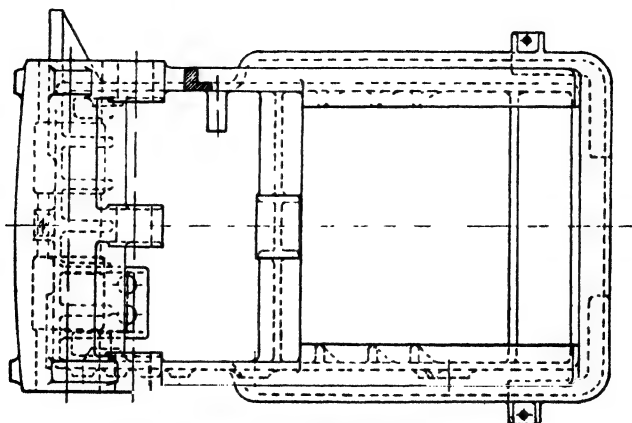



Fig. 4. Plain view, cast iron construction.

Stock	Rate of Cutting Inches per Min.	Cubic Ft. of Acetylene per Min.	Cubic Ft. of Oxygen per Min.	Cost per Inch
½"	18	.2	1.5	$0.0028
⅝"	16	.21	1.8	.0034
¾"	15	.23	2.0	.004
1"	14	.23	2.3	.0045
1½"	12	.27	3.3	.0065

The amount of inches of cutting is computed with the view of using the straight outer edges of the hot rolled steel plates as the straight edges of the larger segments and also arranging the segments so that one cut will serve as the edge of two segments. Where segments are, as in case of segment 4 with dimensions of 1½-inches x 2½-inches, a bar of steel of those dimensions is used and the segments need only be cut to length. In addition, the round bosses when of small diameter can most economically be made of round stock and either sawed to length or torch cut. In a case like our own where a complete machine shop is available and stock is being sawed off at all times, the costs shown here will be by that method. The number of inches of cutting and the costs are tabulated as follows:

Stock	Number of Inches	Cost per Inch	Total Cost
½"	227	$0.0028	$0.63
⅝"	368	.0034	1.25
¾"	39	.004	.16
1"	40	.0045	.18
1½"	5	.0065	.03
Total			$2.25

These cutting costs seem extremely low but with comparatively simple and inexpensive cutting machines and with templates for irregular shaped forms no difficulty will be experienced in cutting these segments and they can be turned out very rapidly.

The total amount of cutting for butt welding, which is used only on both inside and outside of the head where it is welded to the frame and also one side each of front and rear segments where they are welded to the side frames, is 269-inches and is computed at the same cost as cutting the ½-inch thick plate.

The arc welding costs are taken from "The Procedure Handbook of Arc Welding Design and Practice" and are computed as fillet welds entirely since the cost of beveling for the butt welds has already been included, and fillet welds which comprise most of the welds on this frame are cheaper, faster and easier although welded on both sides of the abutting plates.

As Computed Labor.................................... $0.75 per hour
Overhead while using equipment...................... $0.75 per hour

The electrode cost is taken as recommended and is for single-fillet welds only, and where welding is done on both sides in every case the number of inches of welding is figured to do both sides.

Fig. 5. Right-hand side view, welded steel construction.

Fig. 6. Left-hand side view, welded steel construction.

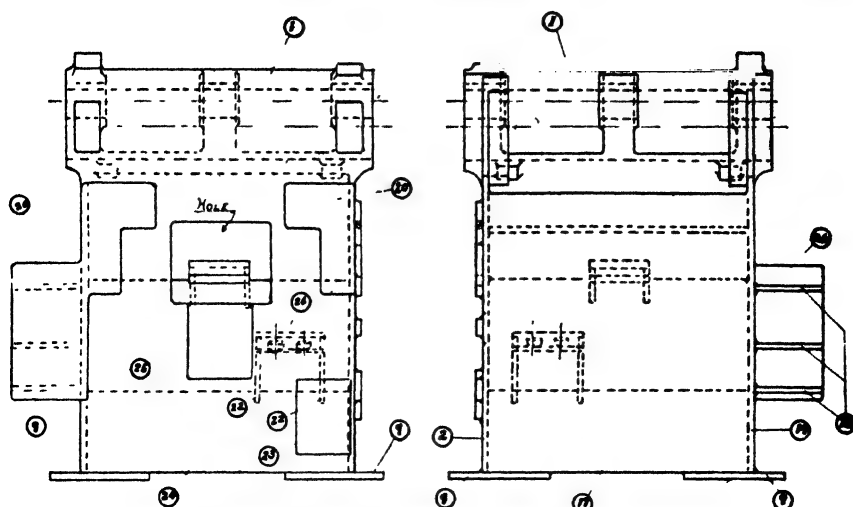



Fig. 7. Front (left) and rear views, welded steel construction.

Stock	Beads	Amps.	Volts	Speed Inches per Min.	Lbs. of Electrode per Inch	Cost per Inch
½"	3	190	30	120	.058	$0.0199
⅝"	5	190	30	60	.124	.0390
¾"	6	190	30	48	.152	.0501

In all cases where ½-inch plate is abutting any other plate, 3 beads are used and where ⅝-inch plate is abutting other plate, 5 beads are used. On ¾-inch plate or thicker, 6 beads are used although in the case of the four feet we could undoubtedly use fewer beads. That, however, is the basis for computing these costs although it is normally left more or less to the discretion of the welder when the segment is not too important.

In the case of the ¾-inch thick bosses there is probably no real necessity to use 6 beads to weld them on; however, a much neater appearance is obtained by the larger fillets.

The amount of fillet welding of the various segments is as follows:

Stock	Number of Inches	Cost per Inch	Total Costs
½"........	108	$0.0199	$ 2.15
⅝"........	542	.0390	21.14
¾"........	67	.0501	3.36
Butt welds........	136	.0398	5.41
Total........	....	....	$32.06

The number of inches of cutting and welding for a frame of this type is extremely small since it can readily be seen from the segment layout on Fig. 13 that most of the segments are large ones, and for the straight surfaces we make use of the edges of the stock purchased, thereby saving a very large amount of cutting. As may be seen, the only amount of welding around the entire base is to attach the foot to each corner.

These figures were taken from the original layout which is too large to include on this paper.

The steel costs are based on quotations submitted by local suppliers when steel was available.

Stock thickness	Cost per 100 lbs.
	$4.07
/8"	4.07
3/4"	4.07
1 "	4.07
1 1/2"	4.32
Cast Steel	12.25

Using these figures as the basis of the stock costs and having computed the segment sizes and weights, the data is as follows:

Stock	Size of Stock	Segment Weight, Lbs.	Segment Cost
1/2"	Plate	234.5	$ 9.54
5/8"	Plate	629.8	25.63
3/4"	Plate	13.8	.56
1"	1" x 10" wide	119.6	4.87
1 1/2"	1 1/2" x 2 1/2" wide	57.	2.46
Bosses	Round stock	11.	.45
Cast steel		470.	57.58
Total			$101.09

From these figures an accurate cost can be derived and is tabulated as follows:

Actual Stock Cost	$101.09
Cost of Cutting	2.26
Cost of Welding	32.07
Fatigue—20% of total time	4.20
Helper @ $0.60 per hour	18.00

Total cost of Frame	$157.62
Total Weight of Frame Stock	1535#
Electrode	99.25
Total Estimated Time	30 hrs.

We have had one cast iron frame cast to date and the computations for the cast will necessarily include the cast of the pattern and core boxes, and we have no definite way of determining just how many of these presses we may have occasion to make and it can honestly be said that the present size of the machine does not conform too handily to the needs of the majority of plants. In all fairness I will assume that over a period of time we may make ten machines from this pattern and will pro-rate the pattern costs in that proportion although there is no guarantee that we will make that many presses.

The data on the cast iron frame is as follows:

Weight	2277 lbs.
Cost @ $6.75 per 100 lbs.	$153.70
10% of pattern cost of $606	60.60

Total cost of frame	$214.30

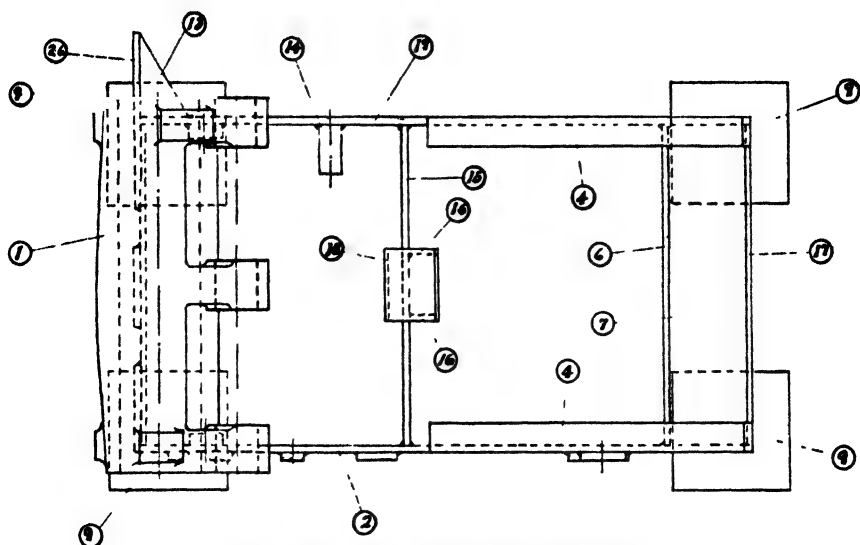



Fig. 8. Plain view, welded steel construction.

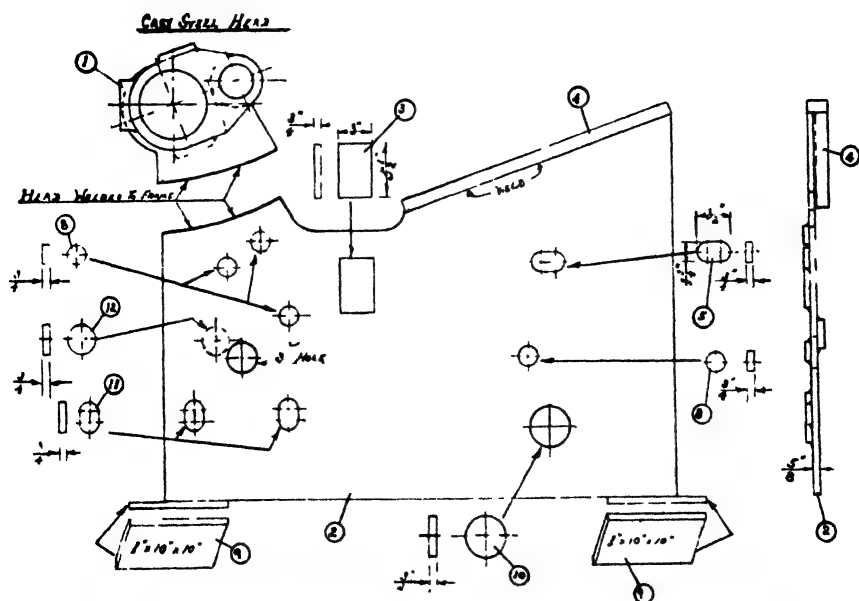



Fig. 9. Dimension drawing right-hand side view welded construction.

Fig. 10. Dimension drawing left-hand side view welded construction.

Fig. 11. Details of parts.

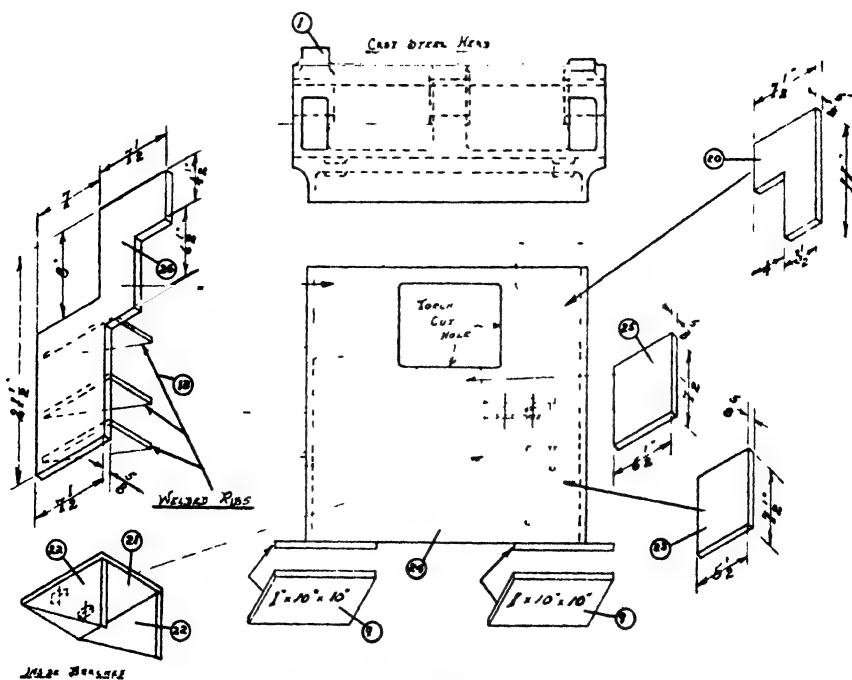
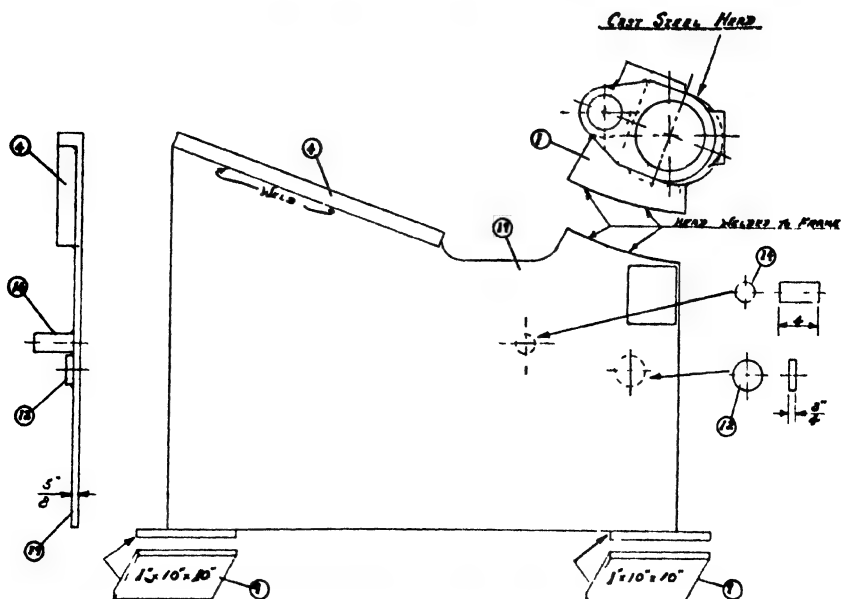
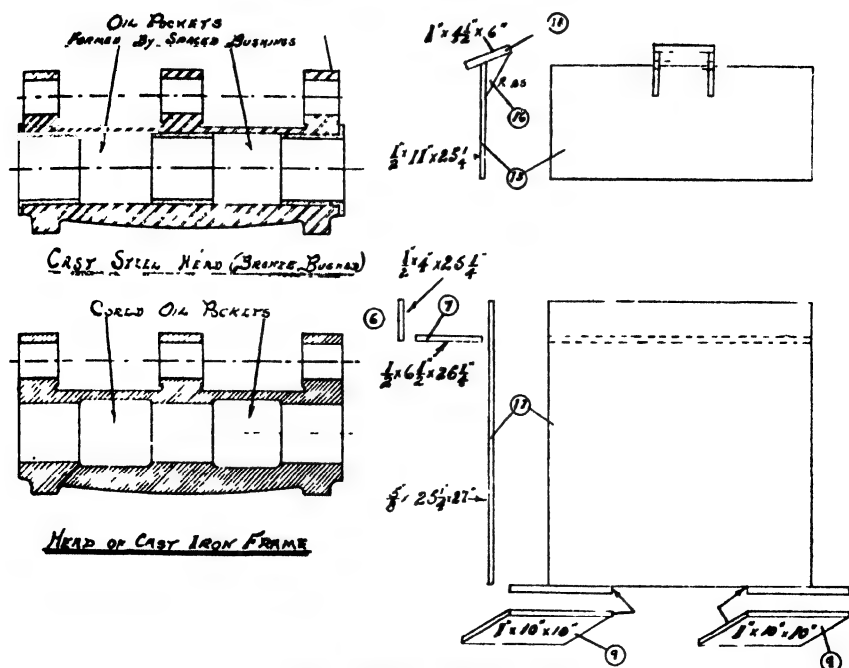



Fig. 12. Details cast iron frame.

From the foregoing figures, it may readily be seen that a great saving in weight is achieved by using the welded frame and also from the figures, which are as accurate as possible. It will be seen that a saving approximately 26 per cent is realized by welding the frame. While there is a certain degree of difference in the appearance of the two frames, they are both made in accordance with the standard practices.

The flare around the base of the cast iron frame is for three main reasons, the first of which is possibly appearance, and to conform to a general trend in machine design, that is more or less current. Then again, it aids in providing additional draft to the pattern for moulding and also allows the weight to be spread over a larger area. Obviously, the type of feet used on the welded frame could not be used on the casting without a good deal of ribbing and even then, with a strong possibility that one of the feet might be broken off in handling or erecting on an uneven floor.

The difference in weight is easily explained by the obvious difference in the thicknesses of the sections and the abundant ribbing which is necessary to reinforce the cast iron.

In the case of the welded frame it may be observed in Fig. 14 that there is normally no particular stress on any welds with the exception of segments 4 which may, provided a die is incorrectly mounted with the load above or below center, be subjected to quite a load. However, both sides of segments 4 are welded to their respective side frames each with total of $57\frac{1}{2}$ inches of fillet welding and have proven amply rigid in the past. This point on the cast iron frame incidentally constitutes our main point of worry, for as you may see on Fig. 1, we have allowed ample metal as shown in the section view and have also provided three ribs on each side.

The figures as given are as close as can possibly be computed and I do

not believe they have been favored in any way. Certainly we are justified in allotting a proportional part of the pattern cost to each casting, and since we have no fixtures at the moment a much greater allowance in welding time was allotted than is actually required. A fair estimate of time was included to peen the corner welds for squaring up after welding which should tend to relieve the stresses that might be set up in welding and eliminate a necessity of normalizing or heat treating.

The finished surfaces on the welded frame are held to a maximum of ⅛-inch and all of the bosses on the side frames are cut ¾-inch thick when the finished dimension will be ⅝-inch and the frame is made closely enough so that amount of finish is ample.

On a casting, and particularly on a large complex casting, ¼-inch or ⅜-inch finish is customary and this can easily be increased by rapping the pattern in the mould so this means more planing time, hence, more expense in finishing.

A further saving is realized with the welded frame in painting because there is no snagging necessary and the rolled plate, being smooth, does not require several coats of filler with the resultant operation of smoothing as is the case with a casting.

Fig. 12 shows the section view through the head of both the cast iron and steel frames and attention is called to the oil reservoirs for the main shaft.

These reservoirs are necessary for the proper lubrication of the main shaft and show bronze bushings pressed into the hole finished in the cast steel head. These bushings are necessary to provide a good bearing surface since obviously we could not run the steel shaft in the cast steel head without them. At the same time, the spacing of these bushings provides the oil reservoirs and since they and the hole into which they are pressed are machined we

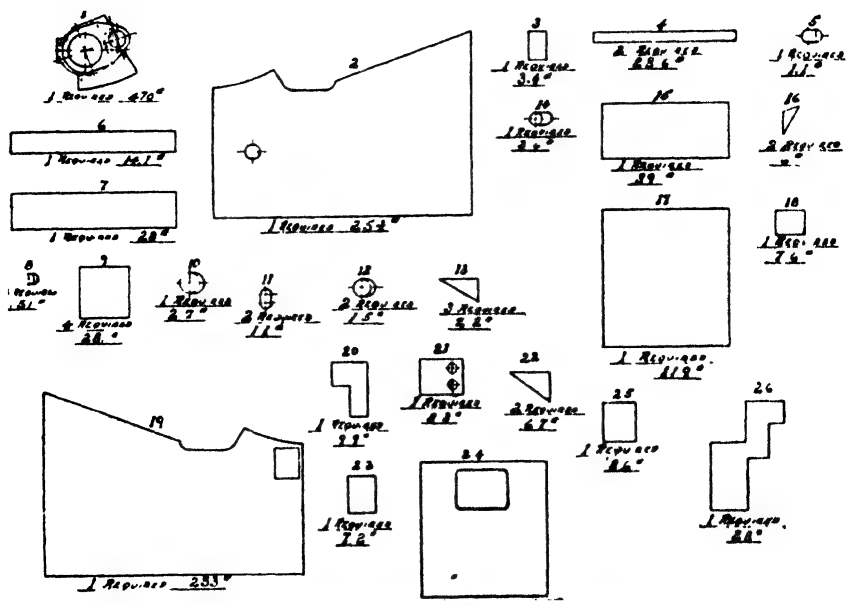



Fig. 13. Number and type of parts required.

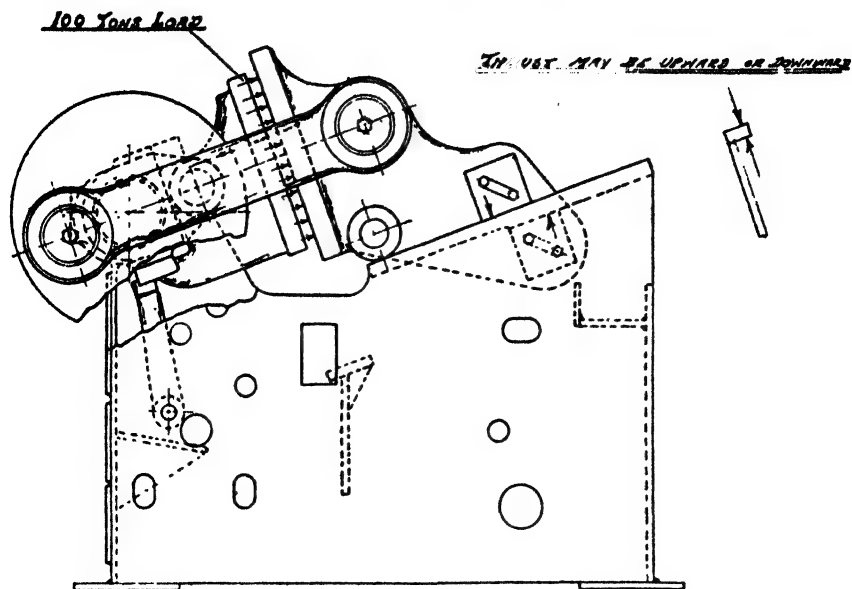



Fig. 14. Load diagram.

can be certain that there will be no chips or core sand which might cause excessive wear as has been the case with the cored reservoirs on the iron frame.

In addition, since the only wearing part on the press is the main shaft hole we are able to install new bushings on the steel frame at such time as the press might come back for rebuilding whereas with the cast iron frame we would have no alternative but to rebore the hole to a larger size and make an oversized and mongrel shaft. Therefore this feature, although made necessary, is a distinct advantage.

The difference in weight is also quite important since not only is the frame easier to handle throughout our operations here in the plant but also the difference of weight of ¼-ton will be reflected in cheaper shipping costs. Quite often elevator capacities have to be considered and this difference in weight could mean that a press might be shipped assembled rather than in sections involving an expensive assembly job with inadequate handling equipment in some factory outside.

Obviously, we have no alternative but to use cast iron frames for the duration and to the best of our engineering skill they should serve the purpose satisfactorily, but when the war is over there will be plenty of first-class welders available. Steel should, due to the great expansion of facilities to make it, be very cheap to purchase and the same will hold true as far as the production of oxygen, acetylene and welding rod is concerned. Then, I am sure, the advantages in welded construction which have been shown in this paper and which have been realized so recently in the construction of tanks, planes and guns will be adopted quite generally.

Chapter XXXVIII—Collating Machine of Improved Design

By John M. Riordan

Chief Engineer, Bonnar-Vawter Fanform Co., Cleveland, Ohio

John M. Riordan

Subject Matter: Heavy-printing-industry machinery is being made from traded-in obsolete equipment and scrap from various places. The finished product does not have the fine appearance of a show machine but it is substantial, economical and efficient. By surveying the old material on hand, good designs can be made when it becomes necessary to do so. This company received orders for several collators, which are used to gather previously printed forms with carbon sheets between each form. War priorities made it impossible to use new materials or to get sub-contractors for the large machining work. Therefore, the machine had to be designed for available material with large parts already machined. The frame and rails were built up from largely-used material by welding short pieces together. Cost of this machine was only 78% of the one previously built. Building time was reduced 31% and the weight was reduced 68%.

The text of this paper will deal with ways and means of building machines or equipment by the new modern method of arc welding.

Without efficient arc welding equipment, the cost and means of obtaining new equipment for the industries in the so-called "second line" non-defense plants are prohibitive, yet these industries are called upon to furnish essential products for defense plants and even the government.

It is true that sometimes priority ratings are furnished with these orders, a degree priority for this and a degree priority for that, and a flock of these priorities has no value if the material is not in some distributor's stock or if the distributor demands a higher degree rating. When this situation is added up there is no priority on time, and by checking through the obsolete equipment, the scrap pile or elsewhere, suitable parts con be found for the arc welding of construction. Castings can be welded to castings and castings can be welded to steel.

Of course, this finished product is not the class of equipment that can be put in the show window for sale but it is practical, substantial, economical and efficient. There is no priority on this method which comes in very handy for repairs as well.

A design in castings is often prohibitive due to the cost of patterns, the extreme weight incurred for strengthening and ribbing, and also because of the molding, handling and machining time. Often-times the detailed welded part cost is less than the pattern would have cost and the molding, handling and machining time is saved.

By applying the science of arc welding in designing machinery and equipment, there is less need for investment in expensive machine tools and space. This method places the small shop operator in a more independent position whereby he can help himself in times like these.

Description of Collator and Product—This machine is known as a collator to the printing industry and is used to gather or collate previously printed forms in register, with carbon paper placed between each sheet.

Fig. 1. The subject of study.

Before passing under the cutoff knife at the delivery end of collator, each sheet of paper has been printed, holes punched along edge and wound up as a roll not to exceed 24-inches diameter 20-inches wide These printed rolls are then placed on the collator on their respective shafts at 28-inches spacing, the length of collator The paper is then run over several other rolls for the purpose of feeding, guiding and squaring up before going over the registering drum which has bullet nose pins at the same spacing as the holes in the paper Each sheet of paper passes over a registering drum; between each roll of paper and above the paper roll shafts are eight other shafts for the carbon paper rolls The first sheet of paper to leave the collator is the bottom sheet of the snapout form, then a sheet of carbon is fed in and passed over the glue wheel, the next sheet of paper, after passing over a registering drum, is run over the same glue pot, but contacts another glue wheel so that when these three parts meet over the next registering drum, they are glued together by the pressure of a rider wheel above the registering drum

The other sheets of paper and carbon are glued the same way so that they are all glued as one

This continuous web is then fed on through to the front of machine where the edge with holes is trimmed off and a stroking means is provided to cut snapout forms to specified lengths and after packing they are ready to ship.

This type of collator is considered the most efficient method and the results prove the high degree of register maintained

Planning and Erection Procedure—Our company built two collators of different designs and after a period of over two years found that one was far superior to the other and as the demand grew for this type of work it became necessary to build another collator to meet the increased production schedule.

So, on December 22, 1941, an order was issued from the front office for one nine-part drum-type collator

The frame of the previously built nine-part drum-type collator was of such size and weight that the work had to be done in a shop equipped to handle heavy structures. The weight of each unit is 3300-pounds and, therefore, it was built in three sections to facilitate handling and, owing to the design, had to be drilled and bored on a boring mill.

In a short time the writer realized what a big change in conditions a few years can make. On our first drum-type collator, the blue prints were sent out to three or four shops for estimates on the various parts and we did the assembling at our shop as we are only equipped in the machine shop for repair work. But today, it is almost impossible to find a shop that will give you an estimate and a delivery date at figures that will meet your budget. We found out that some of the material was not on the market any more.

Therefore, the machine had to be redesigned for available material, light in weight, simple in design so that we could handle and machine the parts in our own shop.

After shopping and scouting around in our morgue, I got a list of materials and in due time the drawings were finished.

The new design of the body or frame of the collator had a length of over 21-feet which means that the three horizontal side rails on each side were welded together, as this size stock only comes in 12-foot lengths.

After welding, they were cut to 21-feet, 1-inch long, keeping the welded joints between the spacers and straighteners. While the drawing calls for 3/4-inch thick stock for the side rails, we were compelled to use some 1/2-inch and 5/8-inch thick stock with the 3/4-inch, keeping one side straight so as to maintain the 18-inch final outside width of frame.

The next operation was to weld the three side plates to the end angles, properly spaced and squared. Then the vertical spacers were welded in place properly spaced and flush with the outside, also the 3/4-inch x 1 3/4-inch straighteners.

At this point, the two frames were placed together outside to outside, squared and matched up, clamped together and doweled, all holes laid out and drilled, reamed or bored on a radial drill. The frames were then separated. The 1 1/4-inch inside diameter bushing hole collars were bored in lathe and cut to length. A slip fit shouldered plug was used 2-inches long and slipped into hole with collar located and the collar welded to frame; the slip plug was then removed and bronze bushings driven into place. The eight steel tubes were then driven into place in one side frame, then the other side was pressed over the other end of tubes with the gas pipe spacers in place and clamped together. The tubes and pipe spacers were then welded to the side plates. The frame was then squared up in relation to the holes and the two cross braces at the ends welded into place; the bushing holes were then lined reamed.

The four angular placed foot braces act as supports for the over hang of weight.

This collator has no extreme weight, speed or shock to deal with. The maximum speed is 150-feet of paper per minute, cut to various lengths. A five horsepower slip-ring A. C. motor we had on hand is used for variable speed control.

Cost Comparison—The machine which was built by the fabricated arc welded method, (See Fig. 1), cost only 78 per cent as much as the one previously made, notwithstanding the fact that labor and material prices had substantially increased. Furthermore, the building time was reduced 31 per cent and the reduction of 68 per cent in the weight of the machine

frame enabled us to handle the parts and do the entire job in our own small shop, instead of trying to have it done outside on heavier machines which were busy on defense products.

We have learned through about five years experience that the possession of an arc welder and the use of it in solving problems not only reduces cost, but also uncovers methods of obtaining results which would otherwise be impossible. We could not have built this machine under present day conditions, without our arc welder. It gives us greater security and a feeling that we do not have to be victims of adverse circumstances. Where there is a will there is a way—by arc welding.

Chapter XXXIX—Redesigned 40 Millimeter Anti-Aircraft Gun Carriage

By Dr. John L. Miller,
Chief Metallurgist, Gun Mount Division, The Firestone Tire and Rubber Co., Akron, Ohio

Dr John L. Miller

Subject Matter: Various parts changed from riveted to welded design The chassis and outrigger supports were redesigned with high-strength low-alloy steels and although only 30% more weight was added, strength was increased 50% Cost per chassis was $76 80 less than riveted construction
The top carriage which carries the gun was redesigned for welding with a net saving of 17-pounds as compared with riveted construction of equal strength Appearance was improved and cost was reduced $10 37, excluding overhead or profit. The axles used in the foreign design were estimated at $110 each when made from solid bars by forging Design, involving tubes and cast steel ends joined by welding, saved about $68 per axle. A number of other smaller parts were also redesigned to be welded The total saving estimated at $171 43 per carriage
While cost is secondary in a military program, the important factor here is the increase in production and the improvement in the performance of the final product

During February, 1941, the Firestone Tire and Rubber Company was approached by the commanding officer of the Cleveland ordnance district, with a request that this company consider the redesign and manufacture of a 40 millimeter anti-aircraft gun carriage This gun carriage was to be made over the lines of the Swedish Bofors Automatic Anti-aircraft Cannon Prior to the time of the request, the army ordnance department had made a complete survey of the manufacturing facilities of plants throughout the United States, and at that time, the use of our company's facilities for the manufacture of defense materiel was volunteered The survey had shown the company to have available a large machine shop, well equipped with modern machine tools and skilled personnel This machine shop had been engaged in the manufacture of various types of molds, dies, and machinery, designed and developed by the organization for its plants located throughout the world Its existence was a deciding factor in the selection of a rubber company for the production of an anti-aircraft carriage

The civil war in Spain had demonstrated the value of an intermediate caliber, automatic cannon for defense of vital supply centers and for defense of field troops against operations of low-flying aircraft During that period, the 40 millimeter Bofors gun proved its efficiency and reliability Since then this gun has been widely adopted, particularly by the British and now by the American forces The decision was based on reports from, and personal observations in, combatant countries and as a result of exhaustive tests of pilot models at the Aberdeen proving grounds

The 40 Millimeter Anti-aircraft Gun and Carriage—The 40 millimeter anti-aircraft gun is mounted on a top carriage attached to a cross bed chassis having lateral outriggers This chassis is mounted on 4 wheels equipped with 6 x 20 transport tires having bullet resisting tubes, all wheels having electric brakes The carriage wheel basis is 126-inches The gun may be

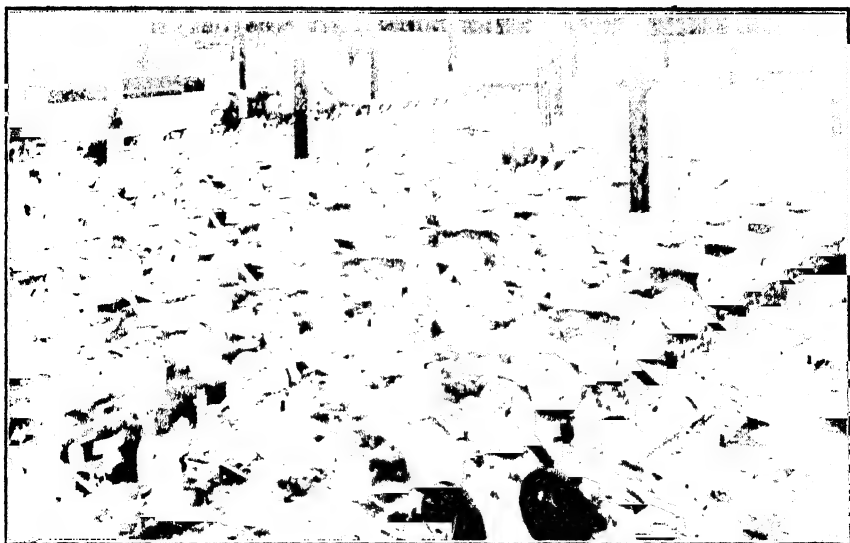



Fig. 1. A panoramic view of a section of the assembly floor showing a number of completed gun carriages ready for installation of gun breech and tube.

elevated from minus 5-degrees to plus 90-degrees or through a 95-degree arc, and may be traversed 360-degrees The projectile has a weight of approximately 2.2-pounds and leaves the muzzle at a velocity of 2,850-feet per second. Shots may be fired at the rate of 120-140 per minute, usually in bursts of 4-6 shells In view of its rapid maneuverability, the gun is adapted particularly to use against low-flying aircraft, including dive bombers. It has a maximum horizontal range of approximately 11,000-yards and a maximum vertical range of approximately 5,400-yards. The effective range is 2,500-yards horizontal or vertical During firing, the gun carriage is supported at four points by jacks having large diameter foot plates and additionally secured by four stakes driven into the ground, guided by brackets attached to the chassis The front and rear wheels are retracted during firing in order to eliminate vibration which would occur if the recoil energy were transmitted to the ground through the rubber tires. This retraction is accomplished by the equilibrating action of strong springs housed within the box girder of the chassis frame The electrical wiring for the brakes, the front and rear lights, and the wiring which conveys current to the motors which operate the oil gears, also are housed within this box girder This is an additional advantage of the box-type construction. Calculation and experience have shown that the box type of construction results in the strongest possible frame for a gun carriage of this type The gun breech and tube are manufactured by another corporation and forwarded to our plant for assembly on the gun carriage. The total weight of the complete gun and gun carriage is approximately 6,000-pounds

The Redesign Period—An important mount was made available for our study. Such drawings as were furnished showed dimensions in the metric system and employed metric or first angle projections. It was required to transpose all these drawings to accord with United States Ordnance Standards, this involving the redrawing, and in many instances the redesigning, of approximately 1,400 separate drawings and the introduction of 460 United

States Government standard data sheets for parts such as nuts, bolts, screws, and washers. Another extremely important transposition involved changes of all materials used in fabrication so as to make them available within the United States A complicating restriction imposed was the necessity for selection of materials adequate for the intended service but containing a minimum of alloying elements which are particularly strategic. To illustrate this, the English had made a large number of parts using steel containing appreciable quantities of nickel The material changes made almost completely eliminated nickel containing steels In most cases these material changes were accomplished without reduction of the unit area physical properties by taking full advantage of processing and heat treating methods proven by modern metallurgy A total of 1,485 individual parts are required for the gun carriage.

During this period, many design changes were proposed, and approved by the United States ordnance department Important design changes which are saving millions of dollars in machine tools and in man hours of labor are the employment of welded construction, the use of a single ball thrust bearing instead of a double constructed ball thrust bearing for the traversing gear, the elimination of thrust bearings in the elevating gears, the use of anti-friction bearings made from powdered and sintered metals instead of solid bronzes, a tubular welded axle construction instead of a forged axle, a change in the method of mounting the gun trunnions on the top carriage, the employment of rubber bumpers instead of a steel spring within the draft connector and the use of four wheel electric brakes instead of two wheel hydraulic brakes. Of these the most important change was the use of welded instead of riveted construction The ordnance designers had suggested that we investigate the possibility of welded construction for the chassis and top carriage Welded designs for these parts were developed by Firestone, assisted by sub-contractor engineers, and the use of welding extended to include many other compo-

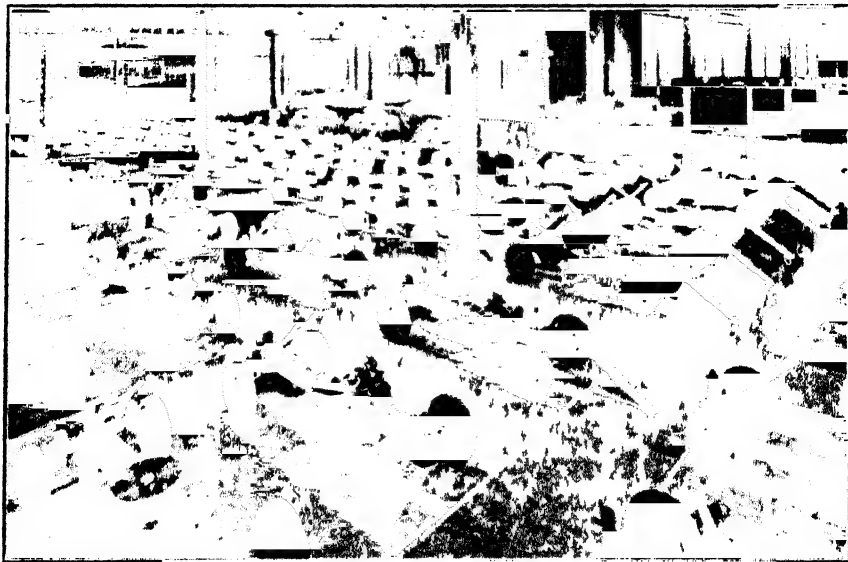



Fig. 2. Another view of the assembly floor showing a number of carriages awaiting assembly of the top carriage and elevating and traversing mechanisms. Completed guns are shown in the background.

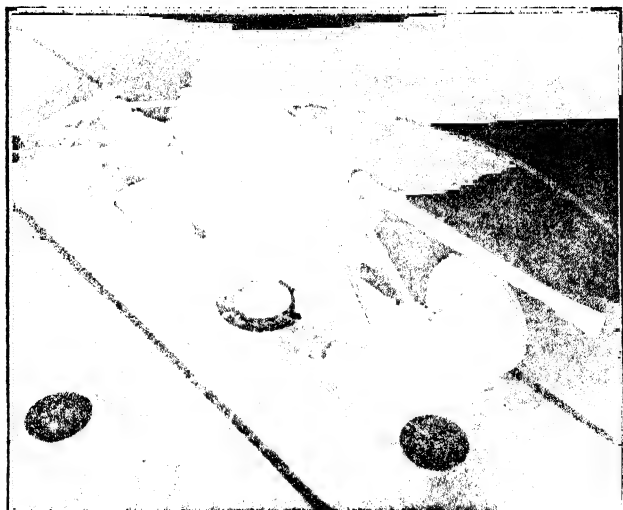



Fig. 3. A 40 millimeter M1 anti-aircraft gun in traveling position.

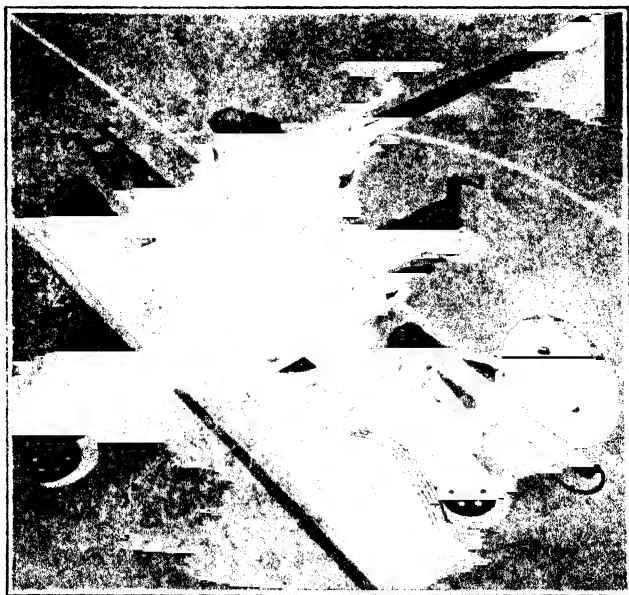



Fig. 4. A 40 millimeter M1 anti-aircraft gun in firing position. This gun is at a station where it is being tested for firing accuracy.

Fig. 5. A close-up view of a completed gun carriage ready for mounting of the breech and tube.

Fig. 6. A close-up view of a gun carriage ready for mounting of the top carriage and gearing mechanisms.

Fig. 7. A close-up view of the riveted chassis sent from England as a model for construction of the 40 millimeter M1 anti-aircraft gun carriage. Notice the riveted construction used throughout.

nents. This redesign was all the more remarkable in that it had to be conducted simultaneously with the transformation from the metric to the American system and with the change from foreign to American materials, with a minimum of time lost in getting into production. The weldability of each material forming part of a welded assembly was carefully considered and chemical analyses controlled to give the best welding characteristics consistent with the designing engineers' strength requirements. To insure relief of local locked-up stresses occurring during welding and during cooling from welding temperatures, it was decided advisable to stress relieve all important weldments Therefore, the minimum design strength of each welded material was determined in terms of its room temperature strength after exposure to a temperature of 1150-degrees F for a minimum period of one hour. Welding engineers and metallurgists will be interested in studying the chemical analyses and physical property data to be given later for a complete appreciation of how this was accomplished The extensive use of the new low alloy, high strength steels is noteworthy.

In order to meet the strength requirements of the army ordnance department—these being much more rigid than those applied to foreign designs—the plates used in the construction of the entire gun carriage were made 50-percent thicker. As the drawings for the redesigned gun carriage were completed, they were immediately used for the construction of parts for two experimental models By adopting such a procedure, it was possible to have these models ready very soon after the last of the drawings had been made. These pilot models were completed in June, 1941, and sent to the Aberdeen proving grounds for testing. Gun breeches and tubes were obtained from a Canadian source and exhaustive roadability and firing tests conducted. These Aberdeen tests proved the general excellence of the redesigned welded carriage, although slight increases in the sectional thickness of a few parts

subsequently were made, an additional strengthening member at the front of the carriage was added, and the draft connector was made longer and heavier. This redesigned and improved carriage is now able to travel at the highest speed of which the prime mover is capable, and, within one minute, be placed in firing position with complete assurance that firing accuracy has not been impaired. This required firing accuracy is dependent as much upon the strength and precision built into the carriage as into the manufacture of the breech and the tube, because the elevating and traversing mechanisms form part of the carriage, and these must be manufactured to extremely close dimensional tolerances. Any lack of gun carriage rigidity during travel or during actual firing would be translated to these mechanisms, causing over-stressing with consequent distortion. This carriage is, then, not only a means of conveyance for the gun, but an integral part of the operation of the gun itself.

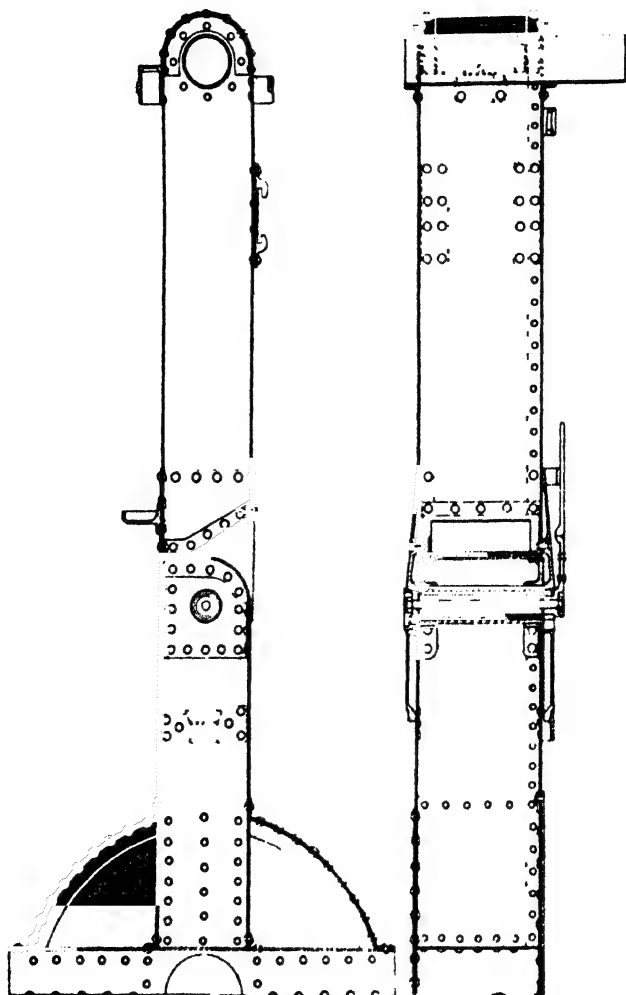



Fig. 8. Line drawings indicating the general features of the riveted construction employed on the English carriage chassis.

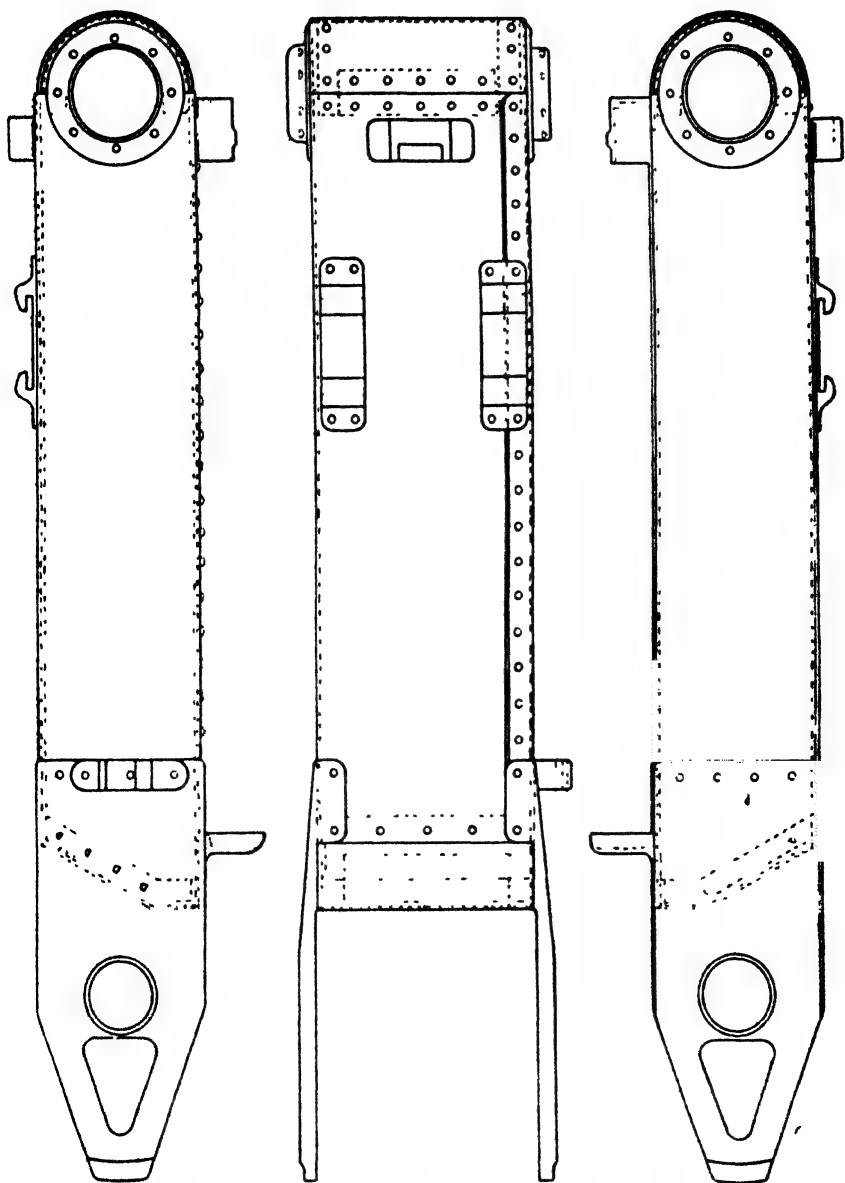



Fig. 9. Line drawings showing the riveted construction employed on the outriggers which form part of the chassis as manufactured according to the English or Swedish design.

Cost figures for the Bofors gun or for the English modification were not available. Because of different wage standards, such cost figures would have been of little value even if available. During the redesign period, detailed estimates of the expected costs of riveted and welded constructions were developed. These estimates indicated that a welded construction would save considerable money and labor, and the employment of welding jigs and fixtures made the welded construction more advantageous for quantity production, with a minimum of delay. The design of carriage details is not static and in a minor way is changing from day to day, simplifications being introduced which result in increased production at less cost. Whatever the design change may be, it is necessary that each important part of sub-assembly be made interchangeable with foreign models and with carriages produced during other stages of our manufacture. This is such an important consideration that many desired changes must be sacrificed.

Organization—In order to accelerate production on this contract, a separate group of buildings and a personnel distinct from that of the parent company were established. Executive, designing, purchasing, planning, materials, metallurgical, machining, assembling, and accounting departments were formed. Close cooperation between each department was essential and each was placed as close to the other as space limitations permitted.

In view of the magnitude of the undertaking, the comparatively short time available in which to get this new undertaking into production, and the desire to make use of the facilities of companies adversely affected by the war industries program, a large number of firms were engaged to supply many of the sub-assemblies. Companies capable of producing certain of the sub-assemblies were asked to quote on a firm price basis The capacity of each sub-contractor to produce parts is closely weighed in terms of the number required to insure a constant flow so that continued assembly is not

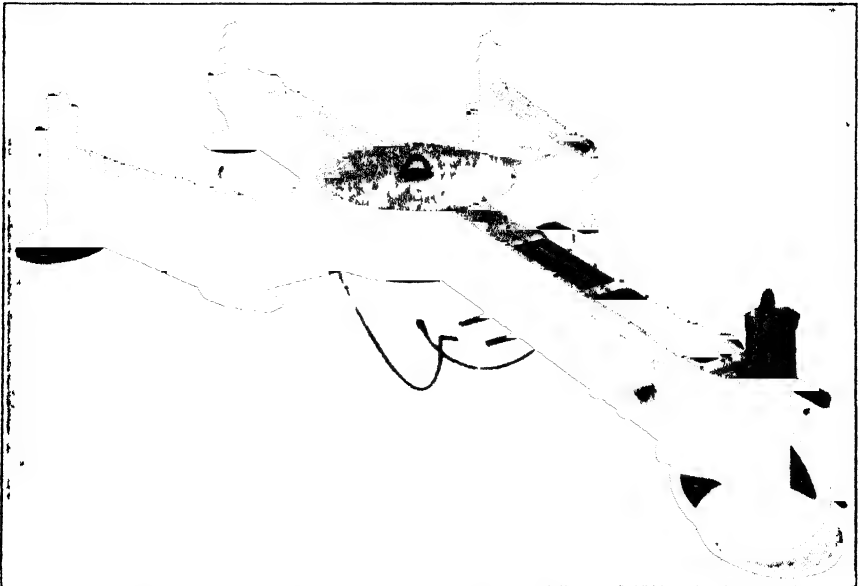



Fig. 10. A close-up view of the redesigned chassis in which welded construction has been employed. This figure should be compared with Fig. 7.

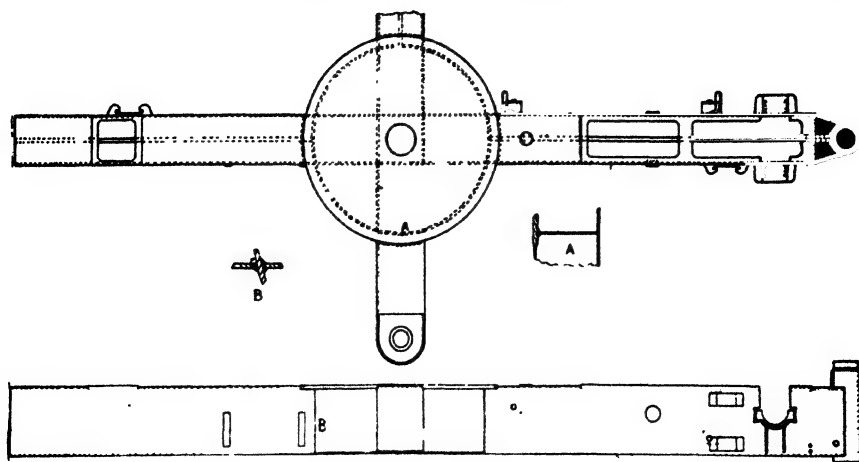



Fig. 11. Line drawings indicating the simplification that has resulted from the employment of welded construction on the main body of the chassis.

interrupted. Since initial contracts for some of the sub-assemblies were placed, it has been necessary, because of production requirements, to let other contracts for the same parts, and today as many as four different firms are fabricating the same sub-assembly. In view of this, actual costs of fabrication necessarily vary from plant to plant. Another factor complicating the establishment of exact cost figures is the continually accelerating program arising from the national emergency. At the time when the first contract was signed, it was decided to establish production on a conservatively low basis. Since that time, the requirements for our company have steadily increased and now exceed by many times the original number.

Although the resources of a large number of sub-contractors are being used, all drawings and material specifications and fabrication directions emanate from the prime contractor and for this reason all methods employed are essentially the same for identical parts. Facilities for the manufacture of this piece of ordnance materiel are being tremendously expanded within our organization, but the requirements of the War Department for this effective piece of equipment have increased to such an extent that two additional prime contracts have been placed. Designs and drawings developed at Firestone are being used by these other two prime contractors.

To indicate the present magnitude of the production schedule, there is shown in Fig. 1 a view of a section of the assembly floor which contains a large number of carriages complete and ready for the mounting of the breech, gun barrel or tube, and automatic control equipment. In Fig. 2 is shown another section of the assembly floor which contains a number of carriages in process of assembly and in the far background a number of completed units, ready for shipment. Fig. 3 shows a view of a completed gun as it is positioned during travel. In Fig. 4 the gun is shown in firing position with the wheels retracted and the entire gun carriage supported and leveled by the four jacks. A close-up view of a gun carriage ready for installation of the breech, tube and automatic control instruments is presented in Fig. 5.

Welded vs. Riveted Construction—The entire frame structures of the original Bofors gun and of the English adaptation of it were riveted. This

included as major items the chassis, the top carriage, and the elevating gear segment. Over 1,000 rivets were required to complete these assemblies.

This discussion is devoted to the advantages of welded design in comparison with the riveted construction employed by foreign manufacturers. In view of the necessity for obtaining greater strength for better roadability, the American carriage is, therefore, necessarily heavier than the English or Bofors constructions. In order to obtain a comparable picture of the weight advantages accruing as a result of the employment of welded rather than riveted construction, the data as presented will show the actual weight of the American model sub-assembly, the weight of the corresponding English riveted sub-assembly, and finally what this weight would be if riveted construction were used and if the section thicknesses were the same as employed in the American model.

The Carriage Chassis—At present, three sub-contractors are engaged in the manufacture of the chassis. Each contractor for each welded sub-assembly is required to train welders so that they may be able to qualify in accordance with the requirements of Federal Specifications WXS-31, "Welding of Steel, Arc, General Specifications For", and AXS-476, "Radiographic Inspection of Welds". To qualify for welding, each welder is required to make butt and fillet type test plates. If the surface appearance is judged satisfactory, these test plates are then X-rayed in accordance with government specification requirements and, if acceptable, the test plates are then stress relieved in a manner identical with the method employed in the treatment of the sub-assemblies on which the welder is expected to work. Three tensile test and three bend test specimens are then machined from the stress relieved plates and tested to determine if the weld metal satisfies the specification requirements for the materials being joined. These tests are conducted under the supervision of government inspectors of the Ordnance District in whose territory the welder is to work. At least one month of actual welding under

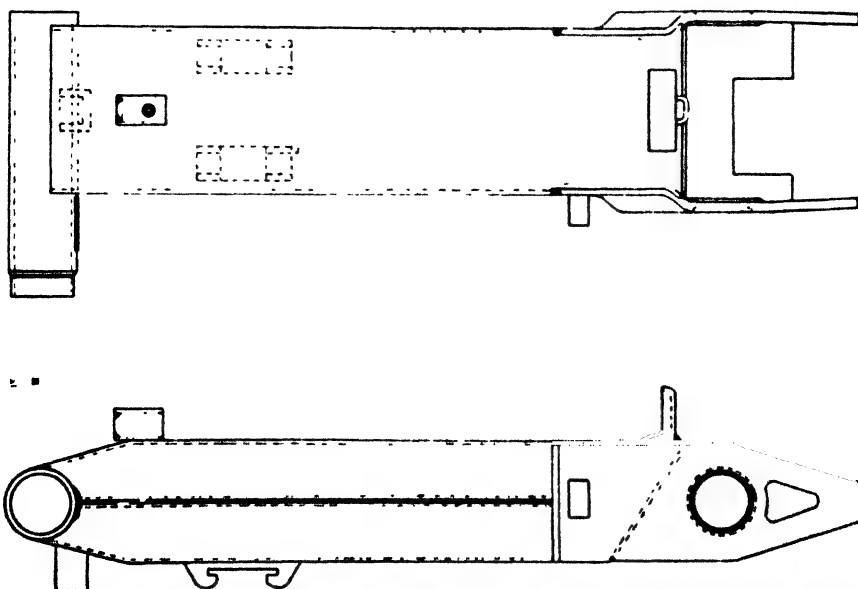



Fig. 12. Line drawings showing the welded design employed on the outriggers which attach to the main body of the chassis.

the direction of a competent supervisor is required to train an inexperienced welder so that he is able to meet government specifications.

As indicated in Figs. 6 and 10, this chassis is of the box-girder type, having two outriggers. The steel used in the chassis construction is of the low alloy high strength type, supplied under Federal Specification 57-114-1, Class B, Grade 2. This specification limits the chemical analysis to a maximum carbon content of 0.25 percent, leaving additions of other elements unrestricted. It imposes a physical property limitation of 50,000-pounds per square inch minimum yield strength, 95,000-pounds per square inch maximum tensile strength and 20 percent in two inches minimum elongation. The material actually used conforms to the following approximate chemical composition:

Carbon	.10–.20 percent	Zirconium	.10–.20 percent
Manganese	.50–.70 percent	Sulphur	.04 percent max.
Silicon	.60–.90 percent	Phosphorus	.04 percent max.
Chromium	.50–.65 percent		

The plates forming the box sections are 3/16-inch in thickness and the plates forming the tub or central section are 1/2-inch and 3/16-inch in thickness. All of the sub-assemblies are positioned for welding, the fixtures required usually being manufactured in the plants of the sub-contractors. Plain carbon steel, covered electrodes, 5/32-inch in diameter are used. Experiments had indicated that the use of an alloy electrode was not required to obtain strength equal or superior to the strength requirements for the rolled, forged or cast sections being joined. No special preparation of the joints is necessary and a low carbon steel backing-up strip is employed. 66-pounds of 5/32-inch diameter electrodes are required for the complete welding of the chassis. In Table 1 are shown typical physical properties secured on experimental test plates, which had been stress relieved at a temperature of 1150-degrees F. Included in this table is a typical weld metal chemical analysis as obtained from single bead welds made on 3/16-inch thick butt welds.

Table 1—Physical and Chemical Property Values—Experimental Plain Carbon Steel Welds on Low Alloy, High Strength Steel

Yield Strength Lbs. per Sq. In.	Tensile Strength Lbs. per Sq. In	Elongation % Free Bend Test	Average Chemical Analysis
60,960	84,020	38.0	Carbon 0.15 percent
59,590	79,540	56.0	
55,580	78,900	42 0	Manganese 0.53 percent
58,160	77,790	46 0	
59,910	76,930	44.2	Silicon 0.43 percent
54,440	80,100	54.0	
57,000	79,030	45.2	Chromium 0.31 percent
57,440	78,860	48 0	
53,570	77,620	62 0	Nitrogen 0.015 percent
59,050	77,850	39.5	

Fig. 7 is a photographic view of the riveted construction employed in the manufacture of the foreign models. These riveted features are also made apparent in the line drawings shown in Figs. 8 and 9. Fig. 10 illustrates the corresponding welded construction now being used and in Figs. 11 and 12 are presented line drawings indicating the locations and general features of the welded construction being employed. The welding methods used in attaching brackets, stake supports, outrigger locks, and other parts to the chassis frame, should be compared with the procedure employed in fastening corresponding parts on the foreign model. Detail photographic views which clearly portray these differences in construction are shown in Figs.

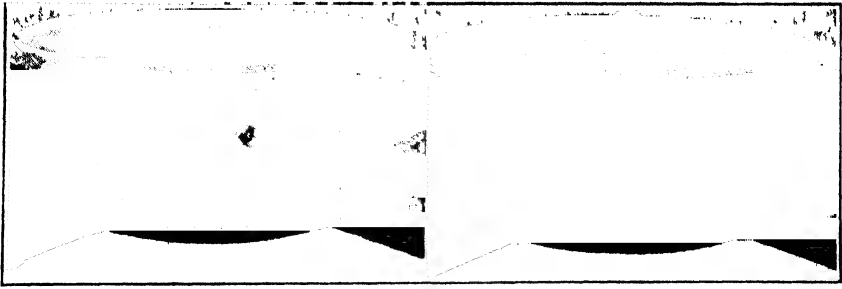



Fig. 13, (left). A close-up view of the tub or central section of the riveted carriage submitted as a model. Note that a slight amount of welding has been used. Fig. 14, (right). A close-up view of the drum or central section of the welded chassis.

13 through 26 inclusive. Figs. 13 and 14 contrast the designs employed in fabrication of the drum or central section of the chassis. Figs. 15 and 16 contrast the designs employed in forming the bottom section of the drum or central section. The foreign design does not completely cover the bottom of the tub. Obviously this would be impossible because of the necessity for getting on the inside to rivet. It will be noted that a double plate is required to secure the needed strength. The welded design consists of a single plate which completely covers the tub bottom, thus adding needed strength without the necessity of having an additional plate. Figs. 17 and 18 are respectively a photograph and a line drawing of the construction employed at the front or swivel end of the foreign model. Aside from the riveted construction, a needlessly expensive method of securing the bearing surface for the axle tube was used. The redesigned model employs powdered and sintered metal anti-friction bearings for the axle tube. The redesigned front end is indicated in the photograph, Fig. 19, and in the line drawing of Fig. 20. The simplified lines and the increased rigidity made possible by the use of arc welding is apparent.

Rigidity Tests—Exhaustive deflection tests to determine rigidity of the chassis in comparison with the imported model were made to check the redesign calculations and the unit strength of the metals and welds in the new chassis. One such test will be described:

Two chassis, one the English riveted model, and the other our welded

Fig. 15, (left). A bottom view showing the riveted construction employed in making the drum or central section of the foreign model. Fig. 16, (right). A bottom view showing the welded construction used in the fabrication of the welded tub.

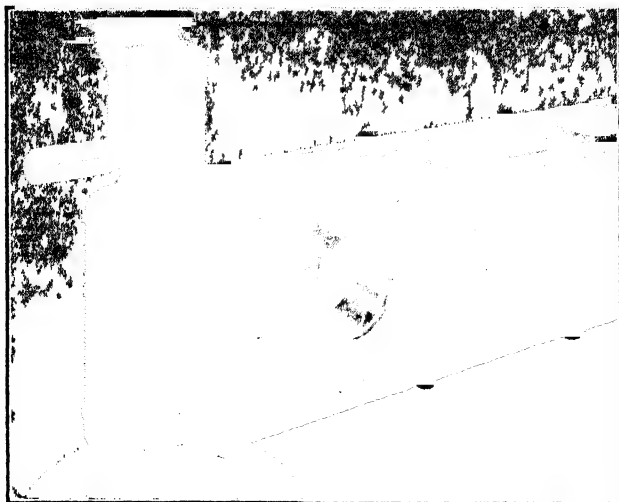



Fig. 17. A close-up view of the riveted design used at the front or swivel end of the foreign model.

chassis, were placed on a level concrete floor in a position as indicated in Fig 6 Six dial indicators graduated in thousandths of an inch then were mounted on separate supports under the central or tub section and positioned in a circle at 60 degree intervals A 3,000-pound weight, which was a static overload of 75-percent, was placed on top of the central or tub section and the deflection noted on each of the six dial indicators This test was repeated several times with the following average results

Riveted Chassis—0 079 inch deflection
Welded Chassis—0 051-inch deflection

The difference of 0 028 inch in favor of the welded chassis corresponds to 028/051 x 100 equals 55 percent greater strength for the welded chassis Both chassis returned to their original positions when the loads were removed, indicating that the stress was completely elastic and that the load was not sufficient to produce plastic or permanent deformation Other similar deflection tests on the front, rear, left and right ends gave corresponding results, all of which were later confirmed by road tests at the Aberdeen proving grounds

The weight of the riveted chassis is 824-pounds and the weight of our welded chassis without the steering support is 1,071-pounds The weight difference of 247-pounds combined with the welded design has produced this 55-percent strength increase The increase in strength resulting from the use of welded construction is therefore 25-percent, calculated as follows·

1,071 — 824 = 247-pounds additional weight

$\frac{247}{824}$ = 30% additional strength resulting from increase in amount of metal used

55% — 30% = 25% *additional strength resulting from the welded design.*

This additional strength is due to the fact that the welded chassis functions as an integral unit under stress The nose piece, shown in Figs 19 and 20, adds greatly to the strength of the front end of the carriage as it forms a rigid support for the steering mechanism This addition, which greatly improves the road performance of the American redesigned model, is not present on the foreign model.

Material Used—In order to insure weldability of all brackets, supports and locks which are attached to the chassis, the chemical analysis of each part was closely controlled and the specifications for physical properties were established with these chemical limitations in mind. In Table 2A are shown the physical property requirements for the chassis parts and in Table 2B, the chemical analyses of the materials used.

Table 2A—Physical Properties of Parts Used in the Chassis

Part Name	Material	Yield Strength Lbs. per Sq. In.	Tensile Strength Lbs. per Sq. In.	Elongation in 2 In. Percent.	Reduction of Area Percent.
Spline Shaft	WD 1035	65,000	81,000	16	....
Eccentric Sleeve	WD X4130	75,000	100,000	20	....
Plate Top	Low Alloy High Str. Stl.	50,000	95,000	20	....
Jack Tube	WD 1020	53,000	64,000	23	....
Backing Strip	WD X1020	40,000	60,000	20	40
Jack Tube Plate	WD X1020	40,000	60,000	20	40
Rib Support	Low Alloy High Str. Stl.	50,000	95,000	20	....
Side Plates	Low Alloy High Str. Stl.	50,000	95,000	20	....
Stake Brkt. Guide	Steel Casting	53,000	85,000	22	35
Eccentric Boss	WD X1020	40,000	60,000	20	40
End Plate	Low Alloy High Str. Stl.	50,000	95,000	20	....
Eccentric Bracket	Low Alloy High Str. Stl.	50,000	95,000	20	....
Bottom Plate	Low Alloy High Str. Stl.	50,000	95,000	20	....
Cap Reinforcing Block	WD 1035	40,000	70,000	20	40
Stake Tip	WD 1035	40,000	70,000	20	40

Table 2B—Chemical Analyses of Materials Used for Parts of Chassis

Material	C.	Mn.	P. Max.	S. Max.	Cr.	Other Elements
WD 1035	.30-.40	.60- .90	.045	.055	....	....
WD X4130	.25-.35	.40- .60	.040	.050	.80-1.10	Mo. .15-.25
Low Alloy, High Strength Steel	.10-.20	.50- .70	.040	.040	.50- .65	Si .60-.90 Zr. .10-.20
WD 1020	.15-.25	.30- .60	.045	.055	....	....
WD X1020	.15-.25	.70-1.00	.045	.055	....	....
Steel Casting	.30 max.	1.10 max.	.050	.065	....	Mo. .40-.65 Si. .55 max.

All of the welds shown in the illustrations and drawings are single bead, plain carbon steel, covered electrode, metallic arc deposits. For the frame proper, a low carbon steel backing-up strip is employed with little scarfing or other preparation of the welded joint required. Pickup of alloying elements from the alloy plate during welding assures weld metal physical properties comparable with the values characteristic of the plate material. Check tests give results similar to those shown in Table 1.

Cost Data—Comparable total labor costs for riveted and for welded constructions were developed for the chassis. The estimates indicated that 282

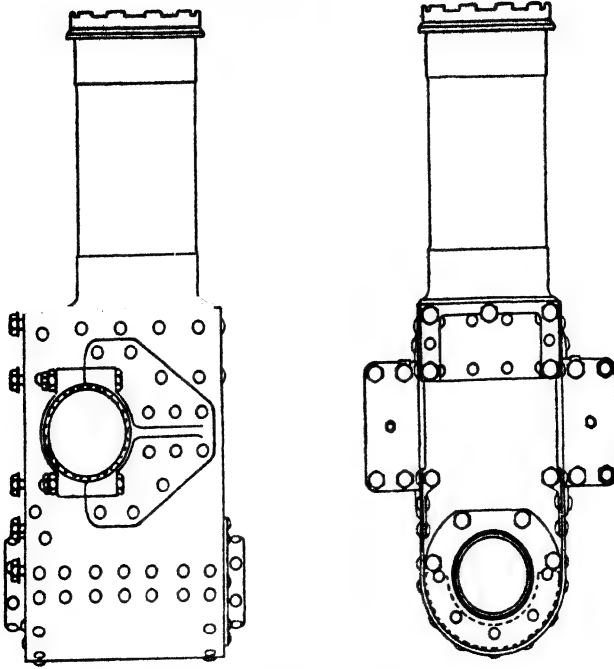



Fig. 18. A line drawing showing the essential features of the construction illustrated in Fig. 17.

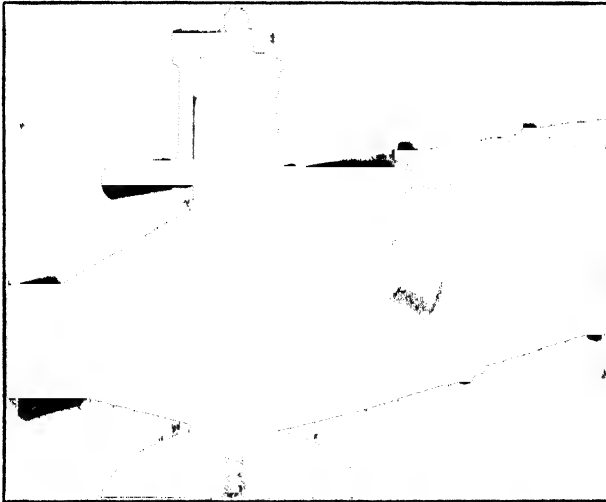



Fig. 19. The front or swivel end of the welded chassis. Note the simplified and weight-saving feature shown for the bearing support. Note also the additional nose piece which greatly adds to front and strength and makes possible travel over much rougher roads.

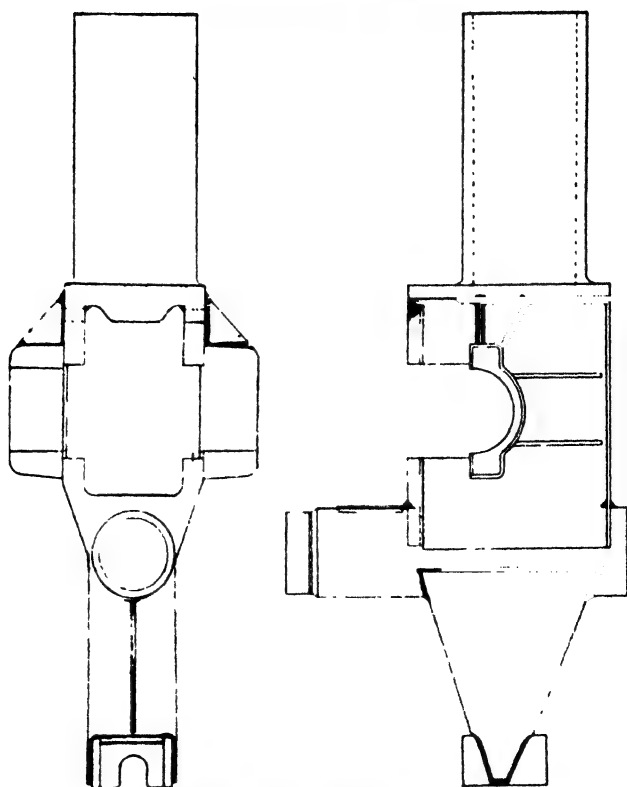



Fig. 20. Line drawing indicating the general features of the welded swivel or front and sub-assembly. In addition to increased strength, the appearance is much improved.

man hours of labor would be required for riveted construction and only 218 man hours of labor for welded construction. A charge of $.004 per pound of metal for stress relieving was applied against the welded construction total labor charge. In these preliminary estimates, assumption was made that the material costs would be about the same and no effort to develop relative costs in terms of material differences was made. Based on an hourly rate of $1.20, this preliminary estimate indicated that a saving of $76.80 per chassis could be effected if welded construction were adopted. Actual costs of welded construction reported during May, 1942, are as shown in Table 3 in comparison with the estimated welding costs.

Table 3

	Estimated Cost	Actual Costs
Material		$167.31
Labor Involved in Welding	$ 68.40	74.80*
Total Labor	261.60	238.20
Stress Relieving Cost	4.34	3.91
Total Cost	433.25	409.42
(This does not include overhead or any profit)		

*The actual welding time exceeded the estimate because of repairs made necessary by critical ordnance inspection.

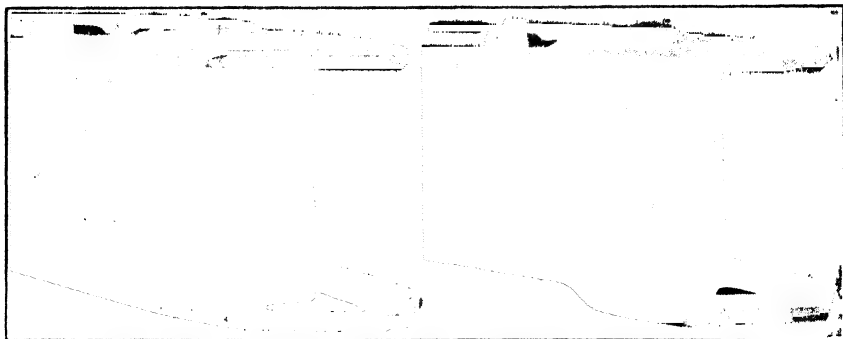



Fig. 21, (left). A view of a portion of one of the outriggers at the location of the swivel. This swivel is used so that the outrigger may be folded into the main body of the chassis during travel. Note in this view that the handle lock is riveted on as is the stake bracket. Fig. 22, (right). A view of the welded construction used for the American made outrigger. Note that the handle lock and stake bracket are also welded.

Top Carriage—After the advantages of the welded construction applied to the chassis had been developed, a study applied to the top carriage indicated that a welded design would be both cheaper and stronger. The redesigned top carriage weighs 300-pounds in comparison with a weight of 264-pounds for the foreign model of riveted construction and a calculated weight of 317-pounds if riveted and of equivalent thickness. This top carriage is made by attaching the uprights to the turntable which is fabricated by the employment of pressed and formed parts welded together. These parts are formed from the same quality steel used in the plate construction of the chassis. The high strength, low alloy steel plates forming the upright box section are punched, placed in welding jigs, and edge and slot welded together. In Fig. 27 is shown a photograph and in Fig. 29 a line drawing indicating the general design features employed in the fabrication of the foreign model top carriage. Comparable views for the weldment are presented in Figs. 28 and 30. Close-up views of the two different types of top carriages are shown in Figs. 31 and 32. The different angle of mounting and the different bearing construction employed for the breech connection are apparent as are the slot type welds used in joining the side plates to the

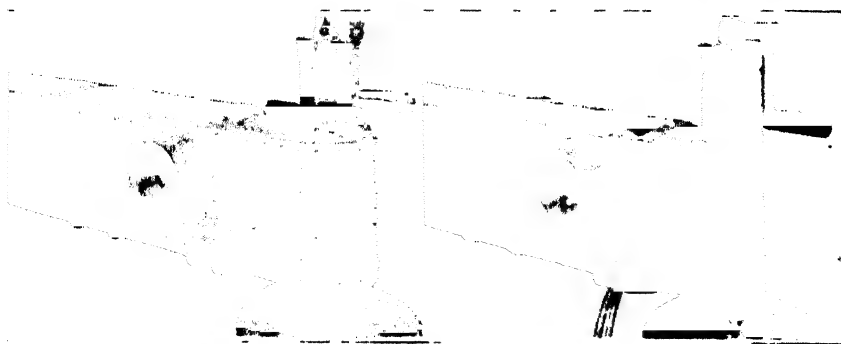



Fig. 23, (left). A view of the rear end of the riveted chassis. Note that the stake guides, the bearing supports and other parts are attached by riveting. Fig. 24, (right). A view of the rear end of the welded chassis. The bearings are of the powdered metal anti-friction type, which have recently gained favor in this country.

internal stiffeners. The physical properties and chemical analyses of the steels used in the fabrication of the top carriage are presented in Tables 4A and 4B.

Table 4A—Physical Properties of Parts Used in the Top Carriage

Part Name	Material	Yield Strength Lbs. per Sq. In.	Tensile Strength Lbs. per Sq. In.	Elongation in 2 In. Percent.	Reduction of Area Percent.
Turntable	Low Alloy High Str. Stl.	50,000	95,000	20	....
Side Plates	Low Alloy High Str. Stl.	50,000	95,000	20	....
Base Bearing	WD 1020	40,000	60,000	20	40
Brackets	WD 1020	40,000	60,000	20	40
Spacers	WD 1020	40,000	60,000	20	40
Bearing	WD 1020	40,000	60,000	20	40
Boss	WD 1020	40,000	60,000	20	40
Clip	Low Alloy High Str. Stl.	50,000	95,000	20	... ..
Bushing	WD 1035	65,000	81,000	16	...
Spacers	Low Alloy High Str. Stl.	50,000	95,000	20	...
Body Tube	Low Alloy High Str. Stl.	50,000	95,000	20	
Stop	WD 1020	40,000	60,000	20	40

Table 4B—Chemical Analyses of Materials Used for Parts of the Top Carriage

Material	C.	Mn.	P. Max.	S. Max.	Cr.	Other Elements
Low Alloy, High Strength Steel	.10-.20	.50-.70	.040	.040	.50 65	Si. .60-.90 Zr. .10-.20
WD 1020	.15-.25	.30-.60	.045	.055		....
WD 1035	.30-.40	.60-.90	.045	.055		......

The preliminary estimated cost comparison for the riveted top carriage and actual costs for the welded one are shown in Table 5. A detail of the estimated cost of riveting in comparison with the actual cost of welding is given in Table 6. The information given in this table typifies the procedure followed in the studying of all the weld redesigned parts.

Table 5—Material and Labor Costs for Fabrication of Top Carriage

Part Name	Riveted Construction Estimated Costs			Welded Construction Actual Costs		
	Material	Labor	Total	Material	Labor	Total
Turntable	$55.00	$6.94	$61.94	$47.00	$6.94	$53.94
Side Frame Parts	9.98	8.72	18.70	10.20	6.45	16.65
Side Frame Parts	9.97	8.76	19.14	10.19	6.49	16.68
Side Frame Assembly	.39	3.34	3.73	.22	3.53	3.75
Side Frame	.39	3.34	3.73	.22	3.53	3.75
Top Carriage Assembly	.64	1.44	2.08	.45	6.39	6.84
Top Carriage Machining	.38	14.94	15.32	.38	14.94	15.32
Body Tube Assembly	2.12	3.48	5.60	2.12	3.48	5.60
Totals	....	....	$129.83	....	....	$122.53

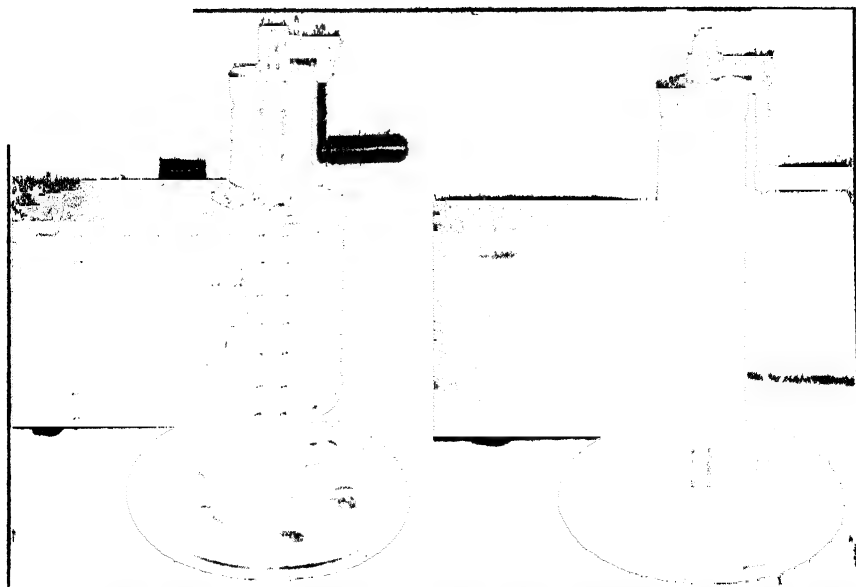



Fig. 25, (left). A view of the extreme end of one of the outriggers of the riveted model. Fig. 26, (right). A view of one of the outriggers of the welded chassis.

Table 6—Detail of Costs on Top Carriage—Riveted vs. Welded Construction

Part Description	Riveted Construction Estimated Costs		Welded Construction Actual Costs	
	Material A	Labor B	Material C	Labor D
Turntable, cast or forged base Welded base	$55 00	$6 94	$47 00	$6 94
Side Frame Parts B requires 7 drilled holes for rivets	46	76	46	.62
Side Plate — 2 required B requires 43 more holes than D but no additional piercing charge is warranted	4 28	3 20	4 26	3.20
Spacer Additional flange required for A to permit riveting B is greater than D as 44 rivet holes must be pierced	40	30	27	08
Bearing Base B requires four pierced holes for riveting	2 32	68	2 32	60
Bracket B requires one added hole drilled	1 23	53	1 24	.51
Mounting Bracket B requires one added hole drilled	16	38	1 16	36
Bushing.	17	28	17	28
Spacer Additional flange required for A to permit riveting B requires 24 holes for riveting	14	28	07	16
Spacer Additional flange required for A to permit riveting B requires 22 holes for riveting	14	27	.07	.16
Spacer — 8 required Riveting requires 68 tubular spacers.	68	2 04	.16	.48
Totals.	$64 98	$15.66	$57.20	$13.39

Table 6 (Cont'd)—Detail of Costs on Top Carriage—Riveted vs. Welded Construction

Part Description	Riveted Construction Estimated Costs		Welded Construction Actual Costs	
	Material A	Labor B	Material C	Labor D
Side Frame Parts	$ 9.98	$ 8.72	$10.20	$ 6.45
Same as above plus parts listed below:				
Boss	.01	.06	.01	.06
Bearing	.09	.08	.09	.08
Clip — 2 required	.04	.16	.04	.16
Plate	.01	.12	.01	.12
Less Bracket	−.16	−.38	−.16	−.38
Totals	$ 9.97	$ 8.76	$10.19	$ 6.49
Side Frame Assembly:				
1. Weld complete (2½ lbs.)	$ .39	$ 2.72	$ .22	$ 2.91
Rivet complete (68 rivets)				
2. Other identical operations		.62		.62
Totals	$ .39	$ 3.34	$ .22	$ 3.53
Side Frame Assembly:				
1. Weld complete (2½ lbs.)	$ .39	$ 2.72	$ .22	$ 2.91
Rivet complete (68 rivets)				
2. Other identical operations		.62		.62
Totals	$ .39	$ 3.34	$ .22	$ 3.53
Top Carriage Assembly:				
1. Weld complete (5 lbs.)	$ .64	$ 1.28	$ .45	$ 4.29
Bolt complete (32)				
2. Check in fixture		.16		.16
3. Stress relieve (300 lbs. at $0.004 per lb.)				1.20
4. Check in fixture				.14
5. Dress welds				.60
Totals	$ .64	$ 1.44	$ .45	$ 6.39
Machining Assembly	$ .38	$14.94	$ .38	$14.94
Body Tube Assembly	$ 2.12	$ 3.48	$ 2.12	$ 3.48
Totals	$129.83		$122.53	

(This does not include overhead or any profit.)

Elevating Arc—The elevating arc is mounted at the bottom of the breech and engages a gear arrangement attached to the top carriage which permits the gun to elevate through an arc of minus 5 degrees to plus 90 degrees. Photographic and line drawing views of the riveted construction employed on the foreign models are presented in Figs. 33 and 35 and should be compared with that used in the welded design illustrated in Figs. 34 and 36. The physical properties and chemical analyses of the steel parts used in the welded construction are shown in Tables 7A and 7B.

Fig. 27. (left). A view of the foreign model top carriage which employed riveted and bolted construction. The base plate or turntable was made as a forging. Fig. 28. (right). The redesigned top carriage. Greater strength and neater appearance at reduced cost has been obtained.

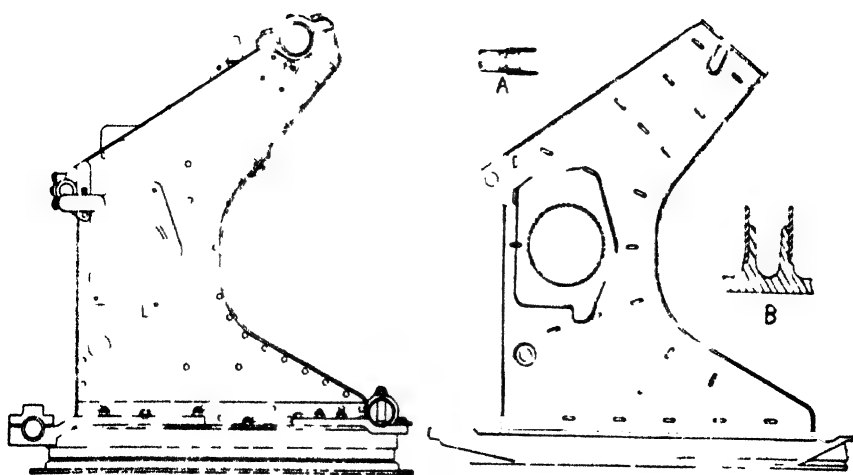



Fig. 29. (left). A line drawing indicating the general features of construction of the riveted top carriage. Fig. 30. (right). A line drawing indicating the general features of the construction of the welded top carriage.

Table 7A—Physical Properties of Parts Used in Elevating Gear

Part Name	Material	Yield Strength Lbs. per Sq. In.	Tensile Strength Lbs. per Sq. In.	Elongation in 2 In. Percent.	Reduction of Area Percent.
Base	WD 1035	55,000	70,000	20	40
Gear Segment	WD X4130	75,000	100,000	20	40
Stop	WD X4130	75,000	100,000	20	40
Side Plates	Low Alloy High Str. Stl.	50,000	95,000	20	40
Spacers	WD 1020	40,000	60,000	20	40
Shim	WD 1020	40,000	60,000	20	40

Table 7B—Chemical Analyses of Parts Used in Elevating Gear

Material	C.	Mn.	P. Max.	S. Max.	Cr.	Other Elements
WD 1035	.30-.40	.60-.90	.045	.055	....	....
WD X4130	.25-.35	.40 .60	.040	.050	.80-1.10	....
Low Alloy, High Strength Steel	.10-.20	.50-.70	.040	.040	.50- .65	Si. .60-.90 Zr. .10 .20
WD 1020	15- 25	30 .60	045	.055	....	....

In order to eliminate cracking and to minimize distortion as a result of welding, all welds are staggered during deposition. This precaution has been necessary particularly in view of the use of heat treated WD X4130 steel for the gear itself. The gear sector is stress relieved at 1150-degrees Fahr. after welding and then it is machined. The same steel thickness was used in both the riveted and the welded sectors and this part offers a direct comparison as to the weight advantage of welding where additional strength is not required. The riveted construction because of the presence of rivets weighs 42-pounds or 3½-pounds more than the welded sector. Such a weight advantage would have been common to most of the weldments in comparison with the riveted construction, had the same steel thicknesses been maintained. Preliminary estimates had shown a welding cost of $2.11 each for the welded gear sector in comparison with a cost of $2.96 for the assembly of the riveted construction. This amount included cost of stress relieving the weldment, which cost

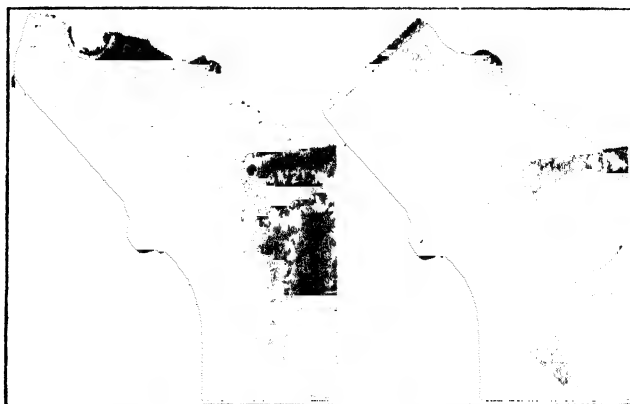



Fig. 31 and Fig. 32. Close-up views contrasting the two designs employed in fabricating the top carriage.

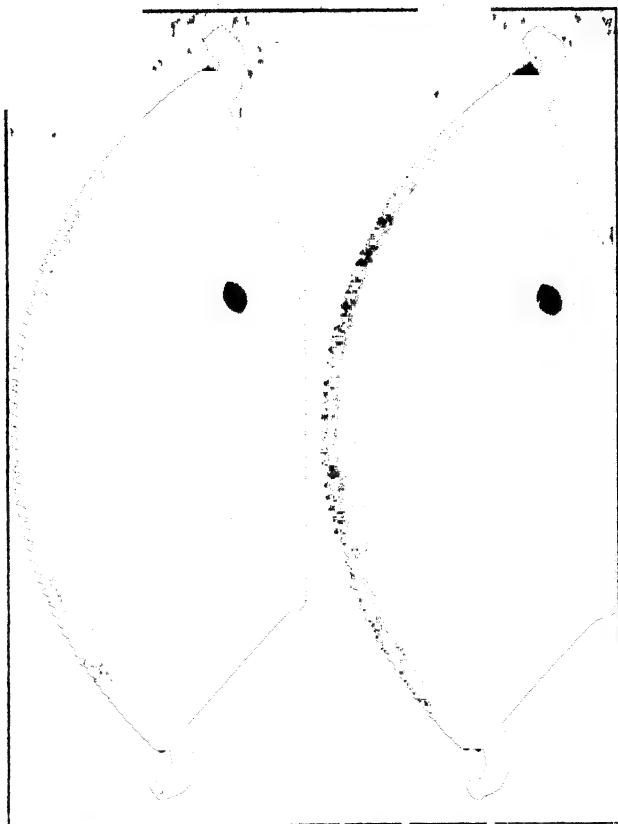



Fig. 33 and Fig. 34. Illustrations contrasting the riveted and welded designs used for the elevating arc sector.

is not involved where riveting is used. The actual welding cost for the gear sector as of May 1, 1942, is $1.61 each, the lowered cost being due to more efficient handling and more rapid welding than had been estimated as possible.

The Front and Rear Axles—The axles of the foreign models had been forged by upsetting the ends of solid steel bars and then they were machined as indicated in Figs. 37 and 38. Such a method of fabrication is relatively very expensive, needlessly wasteful of material and a slow production method. The axles used on the redesigned carriage were fabricated employing WD 1035 tubing, cold drawn and finish annealed to which were welded cast steel heads. These steel castings are purchased in accordance with Federal Specification QQ-S-681, Class 4, which requires a yield strength of 53,000-pounds per square inch minimum, 85,000-pounds per square inch tensile strength, 22-percent elongation, and 35-percent reduction of area. The chemical analysis of the cast heads is as follows:

Carbon	.30	maximum
Manganese	1.10	maximum
Sulphur	.065	maximum
Phosphorus	.05	maximum
Silicon	.55	maximum
Molybdenum	.40 – .65	

The weld joints are prepared by machining before welding. The axles are positioned for welding and welding is accomplished using ¼-inch covered electrode, carbon-molybdenum steel rods. Estimates indicated that material and labor costs of an axle as made in the foreign manner would be $110 as contrasted to an amount of $42.08 for the tube and welded construction. This item is subcontracted and no actual cost data is available to compare with the estimate, but the placing of an additional contract at a price lower than the original indicates that this estimated cost is not being exceeded. Close-up views of the forged and of the welded constructions are shown in Figs. 39 and 40.

Other Parts—Many other small parts used on the gun carriage were redesigned for welded construction. Two such parts are presented in Figs. 41 through 44. Fig 41 illustrates the construction employed in the manufacture of the foreign made stakes. These stakes are used to fasten the gun carriage securely in firing position. A saving of $1.08 per stake has been realized on this small item. The foot plates illustrated in Figs. 43 and 44 are another example of the completeness of the redesign for welded construction. The plates are attached to the four jack screws which are used to support and level the gun carriage while in firing position. A cost advantage of $.15 per plate in favor of the welded construction has been realized.

Another small part redesigned to take full advantage of welding is the

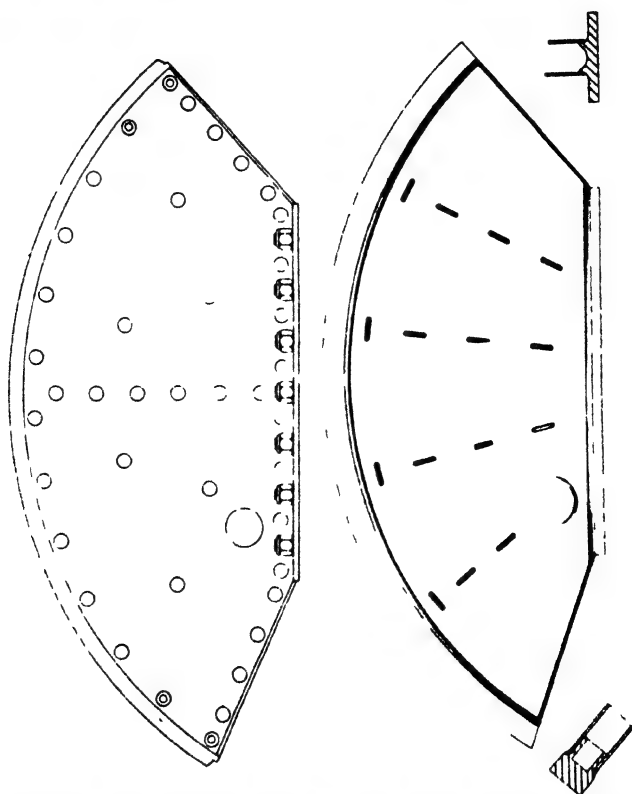



Fig. 35 and Fig. 36. Line drawings indicating the general features of construction for the riveted and welded elevating gear sectors.

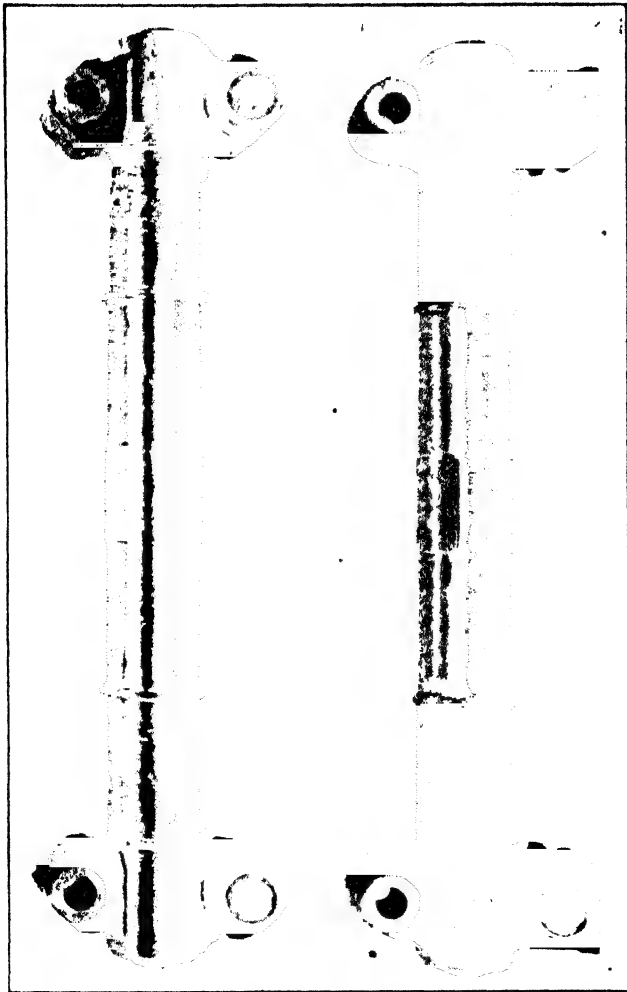



Fig. 37 and Fig. 38. A view typical of the front and rear axles made abroad. A solid bar was upset and forged at the ends and then center bored. This is obviously a very expensive method of construction.

Table 8—Weight Comparisons

Part Name	American Welded Model	English Riveted Model	Calculated Riveted Model
Chassis	1,084	824	1,155
Top Carriage	300	264	317
Gear Sector	38.5	42	42
Front Axle	114	97*	121
Rear Axle	114	84*	108
Stake (4)	21.5	18	22
Foot Plate (4)	9.5	7.5	10.0
Gun Stay	60.5	58.5	62.0

*As previously explained, these parts are not riveted but forged.

gun stay or support which holds the gun tube in a rigid position during travel. This gun stay is discernible in the illustrations of Figs. 3 and 5. Welding is also employed in the fabrication of the equilibrator tubes, the draw bar and the carriage platform. The English model also used welding in the fabrication of these parts and no comparison will be drawn.

Summary of Sub-Assembly Weights and Cost Savings—In Table 8 is shown a summary of the weights for the important redesigned welded sub-assemblies, the comparable weight for the English model and the calculated weight of a riveted design having the same metal thicknesses as are present in the welded carriage.

In view of the nature of many of the sub-contracts, it is not possible to show in a definite way the money savings that have resulted from the employment of welded construction. From the information now at hand, the indicated saving is approximately $160 per gun carriage. This saving appears large until it is realized that the cost of materials, and the cost of the close

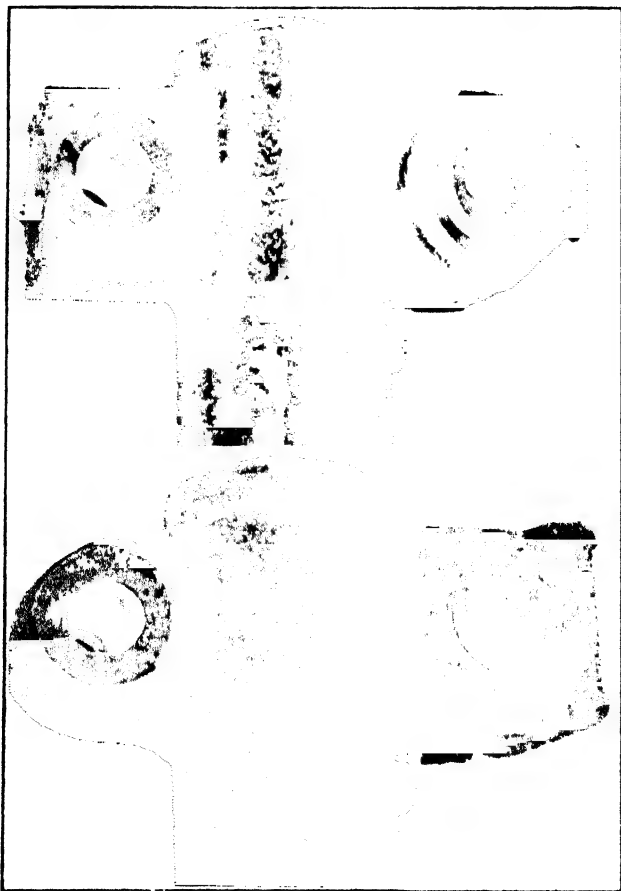
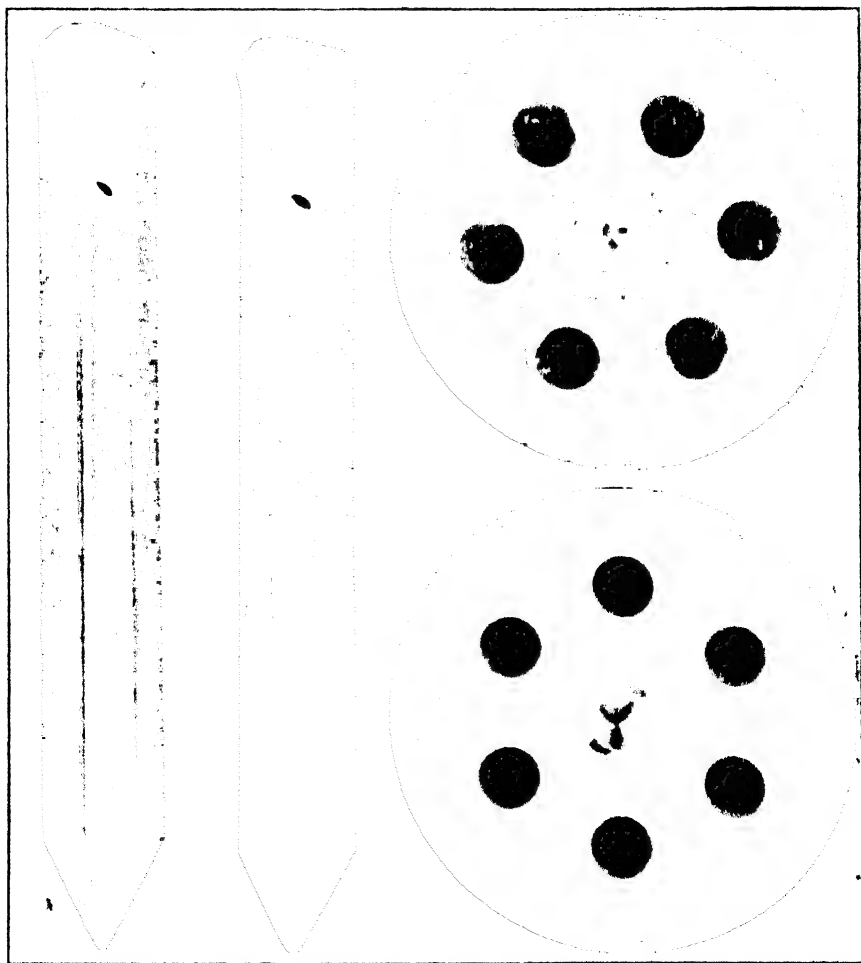



Fig. 39 and Fig. 40. Close-up views of one end of the forged and of the tubular welded axles. The particular advantages of the welded construction include much lower cost and simplification of construction. The design change has made possible a large increase in axle production.

machine work required on so many parts which are in no way influenced by the welded design, makes the actual saving rather small in terms of the total cost of the gun carriage.

Closure—In times as momentous as these, cost in itself cannot be a deciding factor in the determination of a particular ordnance design. Speed of production and efficiency and reliability during field operation are of greater importance. Several design changes were incorporated in the 40 millimeter gun carriage in order to facilitate production and to improve operation. In achieving these results, the most important change was the conversion from a riveted to a welded construction.

Fundamentally, cost is the sum total of the number of man hours of

(Left to right): Fig. 41. (left). Riveted construction employed on the foreign made stakes and the welded construction, (Fig. 42, right), used on the American made stakes. Figs. 43 and 44. Views illustrating the extent to which the redesign for welded construction has carried. The top view (Fig. 43) is of the foreign made riveted foot plate and the bottom view, (Fig. 44), the American made welded foot plate.

labor required to produce a completed unit or number of units. A decrease in cost may be translated to mean an increase in production of units with a given amount of labor. The adoption of the welded design produced an appreciable saving in the final cost of the gun carriages and, therefore, more carriages are now being made within a given period of time.

This mobile carriage is equally well adapted to defensive and to offensive operations. Who knows but that these additional units made available through the ingenuity of designers and engineers, unwilling to slavishly follow a pattern that had been considered good enough by others, will not some day prove to be the deciding factor in achieving victory. Our present huge armament program undoubtedly offers many other examples of American inventiveness directed to this same end.

"For the want of a nail the shoe was lost,
For the want of a shoe the horse was lost,
For the want — — — — — — — — —."
Poor Richard, Benjamin Franklin.

Chapter XL—Improved Synthetic Cleaning Machines

By ERNEST DAVIS,

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Ernest Davis

Subject Matter: By using arc welding procedures, major changes in design, factory cost, weight of machine, and efficiency of operation were possible in a dry cleaning device. An older model, made largely from cast iron, had a shipping weight of 8,800 pounds. The new arc welded model weighed only 2,780 pounds. This reduction in weight, combined with less machining cost, allowed a much greater spread between factory cost and selling price. The new machine was also more efficient. About 50% more garments could be cleaned per hour while the solvent cost was reduced at the same time from 2¼¢ per pound to ½¢ per pound. Owing to compact construction in one unit, there is less vibration and the cost of installation is considerably less. The author estimates that the saving in solvent cost alone for the entire cleaning industry would be $10,000,000 per year, assuming that all machines in use in the industry could be replaced by a machine as efficient as the one herein described.

Dry cleaning machines, using chlorinated hydrocarbons such as trichlorethylene and perchlorethylene as the cleaning fluid, are classified generally as open or closed types. The main difference in the two being that in the open machine the process of cleaning is carried on, fully open to the atmosphere immediately surrounding the machine, whereas, in the closed machine, the process of cleaning, which includes washing, centrifugal extracting, drying and recovery of the solvent, is accomplished within a closed and sealed compartment, and in an atmosphere entirely independent from that immediately surrounding the machine.

The two machines treated in this paper are the fully enclosed type. The 2 B machine consisted generally of the following units:

A. A combination washer and centrifugal extractor described hereafter as the hydro wheel consisted of a heavy shell or container for the cleaning fluid, and a horizontally disposed revolving and perforated clothes container mounted within the shell. The clothes container, or cylinder was arranged to be driven at approximately 34 revolutions per minute for tumbling the clothes, while washing, and during the subsequent drying operation. After the washing operation the cylinder was revolved at a speed of approximately 500 revolutions per minute for centrifugal extraction, and after extraction the cylinder was again operated at slow speed during the drying operation.

B. A separate drying and recovery unit was provided and connected to the hydro wheel by pipes and flanges. The recovery unit consisted of a centrifugal fan, heater coils, condenser coils, and a heavy cast iron container for these units. Also included in this recovery unit was a water separator, lint trap or air filter.

C. A storage tank of approximately 50 gallons capacity, with heavy cast iron supports for the storage tank and a gravity separator.

D. Distillation apparatus consisting of still, steam heated, still condenser unit, piping, steam traps, etc.

E. A record-type cycle control timer, trade name "Formatrol". This unit completely and automatically controls the entire cycle of cleaning.

While the still unit as well as the storage tank on the old unit was electrically arc welded, the hydro-wheel was mostly constructed of cast iron. There was provided, for this hydro-wheel, a very heavy cast iron base. This very heavy base was deemed necessary because the hydro-wheel was to serve both as a washer and a centrifugal extractor. The inclosure for the recovery unit was made entirely of cast iron, and consisted of one main casting and two end castings. The three castings weighing approximately 600-pounds. As a point of interest in connection with this paper, it will be shown further on, how less than 100-pounds of material in the new machine, and much less labor served to replace this 600-pounds of cast iron in the recovery unit.

For purposes of comparison, this paper will deal mostly with those units or combination of assemblies in which fabricated and arc welded construction replace cast iron or other methods of construction.

The following description, drawings, cuts, etc., will serve to bring out as clearly as possible how, by combining several units into one assembly of arc welded, fabricated plate steel construction, the following results were obtained:

1. Provide a greater spread between factory cost and selling price.
2. More salable because of better appearance, greater compactness, greater capacity.
3. Much higher efficiency in operation, particularly in regard to solvent cost.
4. Less health hazard because of reduction in the number of separate units comprising the complete unit, and therefore reduction of the number of gasketed joints, and possibility for leakage. Also sludge-drying apparatus.
5. Less pattern cost and overhead.
6. Less vibration, smoother operation.
7. Much less shipping weight and floor weight.
8. More reliable operation, more rigid construction because of lesser number of separate units, and because of welded construction, eliminating numerous bolts and holding devices.
9. Less cost of installation.

This paper shall point out, and give reasons for these nine points of improvement. Of course it will be understood that some of the improvements are not due entirely to the method of fabrication, but rather to improvement in design; nevertheless, it may be clearly shown that welded steel construction played a very important part in the total results.

As stated in preceding pages, the old machine consisted of five principal units, A, B, C, D, and E. Now, the new machine consists generally of an equal number of necessary units. For example, washer, extractor, air filter, condenser, and heaters, a blower for the recovering of solvent, a storage tank for solvent, and of course, a Formatrol, as well as many control valves, dampers, traps, etc. But the basis for this paper and the principal proof for the nine points of superiority lie mostly in the fact that in the new 6-A machine all of the five principal units comprising the machine are incorporated in one single steel fabricated arc welded cabinet. This one

fact accounts for a differential in weight between the old and new machine assembly of units of some 2600-pounds of material.

Weights are as follows:

	Pounds	
Old Machine Weights:		(weighs alone almost double total
Hydro-Wheel	3310	(of new cleaner elements.
Heater & Fume Condenser	600	(Note: This recovery unit alone (weighs nearly as much as the (entire welded steel cleaner cabi- (net for the new machine.
Blower	100	
Air Filter	40	
Four-Way Valve	110	
Storage Tank with C.I. Supports	230	
	4390	(This weight is not total, includes (only assemblies listed.
New machine with all the elements above, weighs	1790	(This includes only assemblies (replacing old assemblies.
Difference or saving	2600	Cast Iron @ 4½¢ Total—$117.00

Now, let us examine why this is so:

In the first place, the 6-A dry cleaner cabinet, fabricated of plate steel, arc welded into one single piece, and hot dip galvanized, after fabrication, weighs only 650-pounds, and this single unit incorporates the following:

1. Washing Chamber
2. Filter Chamber
3. Storage Tank
4. Condenser Chamber
5. And all of the air ducts for controlling the flow of air to the machine during the drying and recovery operation. See photographs, Figs. 1 and 2.

In this cabinet design, the washer chamber consists of a single piece of plate steel, ⅛-inch thick, with one horizontal welded seam and two circular welded seams at the two ends, plus an end plate bolted in place for removal of the cylinder. But, more than that, this washer container also forms the top of the storage tank, the bottom of the filter chamber, the front of the condenser chamber, and at the same time serves as a very rigid stress member to tie the cabinet ends together.

The back sheet, Drawing Fig 3, a single plate of ⅛-inch steel forms the back of the condenser chamber, the back of the storage tank, and provides for openings, door-reinforcements, etc., while serving also as a stress member.

Referring to detail sheet, Fig. 4, the front and bottom sheet material, ⅛-inch, forms the bottom of the storage tank; also the front of the storage tank, and serves as a front apron for the washer compartment. This sheet is bent to form a drain for the storage tank. Naturally, this sheet also serves as a stress member to tie the end plates together.

Next we have the detail, Fig. 5, "Frame Top Sheet", forming the top of the machine, the top of the air filter chamber, the front of the air filter chamber and also support for blower fan and motor assembly. The holes
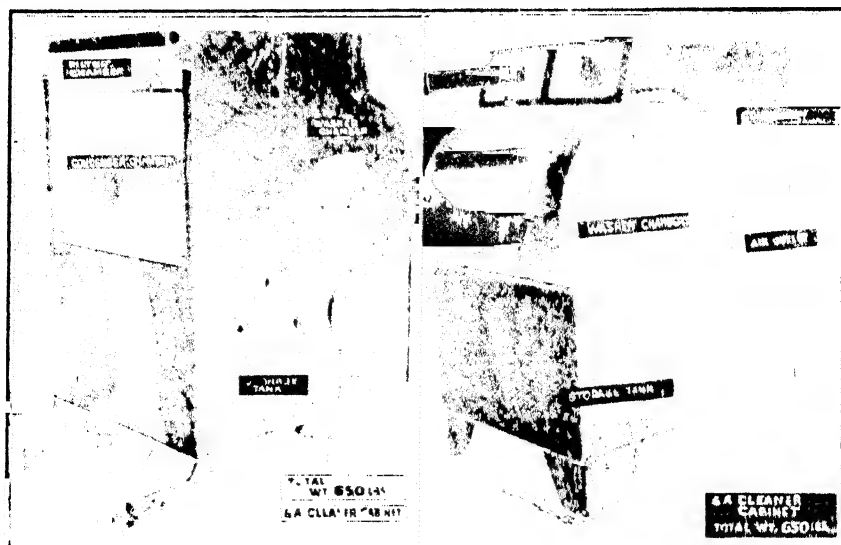
Fig. 1. (left). Arc welded cleaner cabinet. Fig. 2. (right). Another view of the cleaner cabinet.

for the fan inlet and outlet also openings for air filter door are cut by torch in this sheet. This sheet as well serves to tie the cabinet ends together

These plates for the two ends of the cabinet, serve not only as end plates for the cabinet but support the washer shell while forming the two ends of the chamber within the cabinet.

The steel castings forming the bearing housing and air intakes to the cylinder are welded into the end plates of the cabinet.

Not only the cabinet serves all the purposes previously described, but the chambers described also serve in most cases as air ducts during the drying and recovery operation. Because these chambers form very generous sized air ducts, the air horsepower required for drying and recovery is held at a minimum. Also, because the heated air circulates always within a single cabinet, and because there is much less radiation loss, drying and recovery of solvent is carried on much more efficiently in the new 6-A machine.

As stated previously, the old hydro-wheel was provided with a very heavy cast iron base and the wheel in itself was very heavy. Also, the recovery unit which was attached to the wheel was of very heavy cast iron construction. The theory back of combining this weight was to serve as a stabilizing mass for the hydro-wheel during the period of high speed extraction. A very important point in connection with the new 6-A machine is that the storage compartment which holds approximately 65-gallons of solvent weighing 13½-pounds per gallon or a total of 877-pounds is located at the bottom of the cabinet, and of course is integral This seems to have a more stabilizing influence than all the combined masses of cast iron used in the old 2-B machine

From the foregoing, one must gain the impression that the combination of all elements of the cleaning machine inclosed and supported by one single arc welded steel fabricated unit must result in a very large advance in construction of not only this particular cleaning machine, but advances the idea of improvements and economies to be gained by arc welding construction,
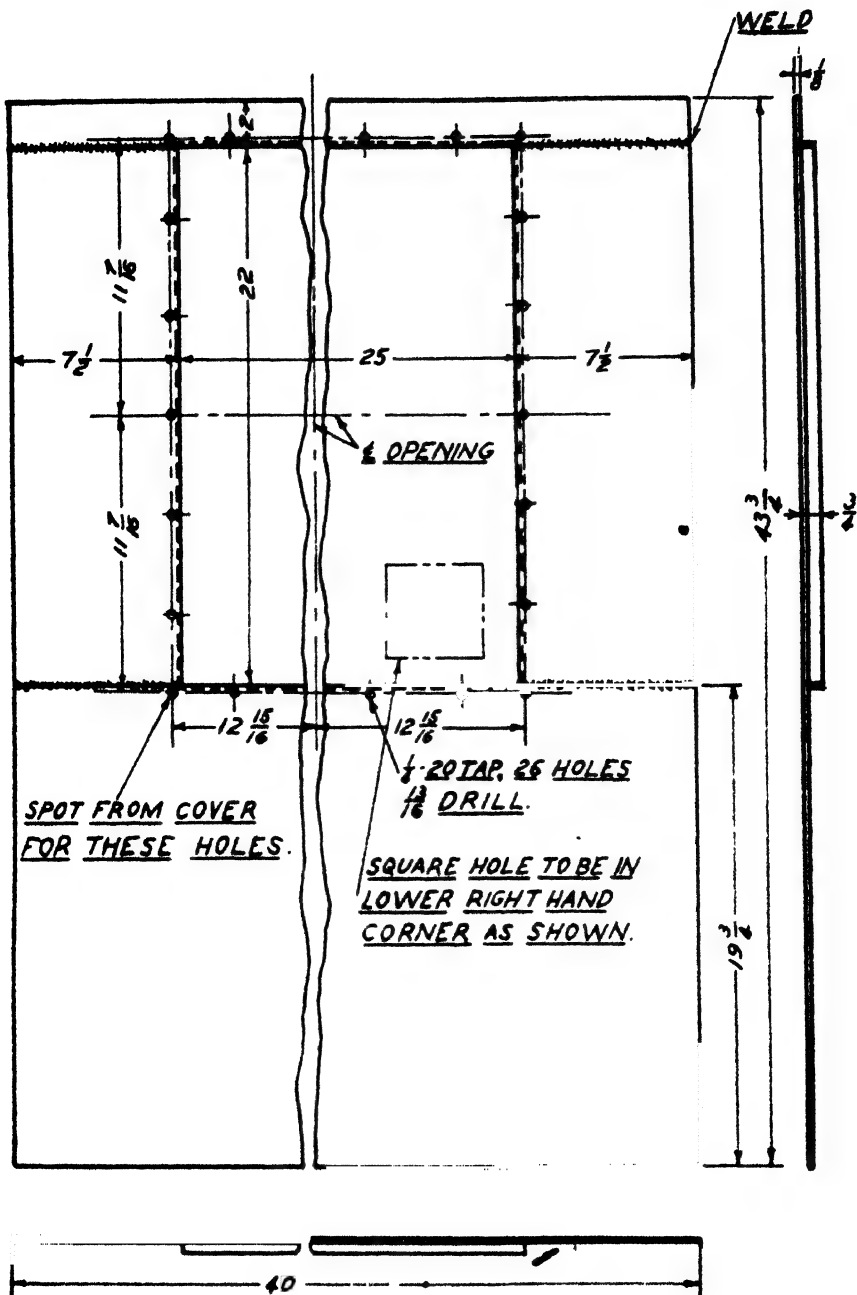
Fig. 3. Back panel, dry cleaner frame.
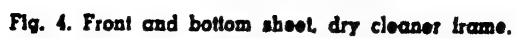
Fig. 4. Front and bottom sheet, dry cleaner frame.

particularly where several such similar units may be combined, and where such combinations would not be practical by any other method of construction.

The Nine Points of Superiority

1, **Greater Spread Between Factory Costs and Selling Price**—Because of the company policy, we can only give the cost differences not too much in detail; however, it is believed that a study of the explanations, etc., contained herein, should indicate a considerable reduction in costs in favor of the new unit of construction. It is believed that the greater spread between factory cost and selling price is completely justified as far as the purchaser is concerned because of the improvements hereafter set forth. The purchaser of the new unit is buying less cast iron and more engineering.

2, **More Salable**—The purchaser generally has become more conscious of the pleasing appearance of dry cleaning machinery. It is believed that a comparison of the photographs, and cuts of the old and new machine will justify contention that the new machine is more salable from the standpoint of appearance. It is more orderly in arrangement, and more compact, occupying somewhat less floor space with the same accessory equipment, such as filters, still, etc. Also, even though the space for clothes to be processed is about the same in the two machines, the time for a complete cycle of cleaning in the new machine, assuming the same quality of cleaning is about 50 percent less, or in other words for the same quality, the new machine has about 50 percent more capacity per hour. This, however, is partly due to the fact that the new machine is provided with a filter, and the old machine was not provided with a filter, and it is also partly due to the more efficient cylinder construction in the new machine, also due to the much higher rate of drying obtained, and recovery of solvent fumes. This increased capacity naturally makes the machine more salable

3, **Much Higher Efficiency, Particularly in Relation to Solvent Cost**—While some of the improvements in the 6 A machine which effected greater economy in the use of solvent are not due to the method of fabrication, it is a point of considerable interest that we find a difference in solvent cost of 4-1 between the old and new machines We have included in this paper some testimonials from customers having the new machine and because of the high solvent cost of the old machine, it was not practical to obtain any testimonials regarding solvent costs with the old machine. The reasons for the difference in solvent costs are as follows:

The particular arrangement of the still condenser in the old machine provided for passage of air through the condenser during the deodorizing operation at a time when this condenser was wet with solvent. This caused a large amount of solvent to be passed to the atmosphere and lost. In the new machine, the arrangement of the condenser is such that it is by-passed during the deodorizing operation, and any solvent remaining on the coils is not lost during this period of operation Again, in the old machine, the heater coils, and the condenser coils which were cooled by cold water, were mounted within the same box and adjacent to each other so that the heat thrown off by the heater coil had a tendency to be absorbed by the very heavy cast iron box surrounding the condenser and heater coils, and a great deal of this heat was transmitted to the condenser coil by radiation and convection. In the new machine, the heater coils are mounted in a small box just outside of the condenser chamber, and the flow of air is such that very little waste heat is absorbed by the condenser coils. Since, in the new machines, the entire cabinet, and practically the entire circuit for the passage

of air is within the cabinet, there is a minimum of loss through gaskets and other possible points of leakage. For the same reason, there is much less loss of heat during this cycle because of the cabinet construction. That is, the air is not passed from one unit through a small opening, out into another entire separate unit. Furthermore, since the hydro-wheel and the condenser unit in the old machine represented a mass of approximately 4300-pounds, as against a little over 1800-pounds for the cabinet assembly of the new machine, there is less loss of absorbed heat.

4, **Less Health Hazard**—Since, in the new machine, we have a single cabinet, constructed in one piece, we have reduced a number of gaskets and possible points of leakage of hot solvent vapors, and because of the more efficient drying and deodorizing, and because the new machine is provided with drying apparatus for drying the sludge from the filter before it is cleaned, there is much less hazard in this latter operation

5, **Less Pattern Cost and Overhead**—The 2-B machine had a large pattern cost of around $12,000, whereas the pattern cost on the 6-A machine originally was about $1,000 Naturally, the upkeep of all the patterns involved in the 2-B machine is considerable, and certainly did not encourage changes in construction even though the changes might be quite advisable When we were ready to build the 6-A machine, only a few patterns for cast iron and steel castings were required and these were very small, both in weight and size. Had we decided later to make the machine a little larger in some dimensions, it was only a matter of changing the drawings and whatever cutting patterns for the cutting torch which had been previously made.

6, **Less Vibration, Smoother Operation** Naturally, when we bind all the separate elements of the machine into a single arc welded unit, so to speak, everything else being equal, we are bound to tie more mass onto the disturbing force which causes the vibration, and this has a tendency to reduce vibration.

7, **Less Shipping Weight and Floor Weight** -The total shipping weight of the 2-B machine was approximately 8800 pounds, and the floor weight approximately 7800-pounds The net weight of the complete 6 A unit, without soap attachments, is given as 2780-pounds, Fig 6 Naturally, this results in a reduction in the cost of shipping It is a little hard to estimate this since the rates vary considerably, depending upon the distance of shipment, and the type of car loading, etc, but since the new machine occupies less space and at the same time very much less weight, it goes without saying that the shipping cost would be almost proportionately less Another very great factor in connection with this question of weight comes up where the machine is to be located, perhaps in an old building, and it is not always feasible to provide reinforced concrete construction, and it is not very practical to mount a machine which operates as a centrifugal extractor on lightly reinforced floor construction. Regardless of whether it is a 2-B machine or a 6-A, there are limitations as to where the machine may be located, but we find that the problem is much less critical with the 6-A machines because of the much reduced weight.

8, **More Reliable Operation**—Naturally, since a 2-B machine consists of many parts bolted together, it is not likely to be as reliable in operation as a machine which more nearly approaches a complete welded steel unit. In the old machine, the hydro-wheel was made up of two end castings, bolted in place on the washer shell, and this wheel was again bolted in place on the heavy cast iron base. Also, the entire drive mechanism was

Fig. 5. Top sheet, dry cleaner frame.

WEIGHTS - LBS	WITHOUT SOAP	WITH SOAP
Cabinet	1825	1825
Filter	510	510
Still & Condenser	305	305
Pipe & Fittings	140	160
Aux Tank Soap	None	145
Aux Pump & Motor Soap	None	80
Base	785	785
Net weight	3565	3810
Solvent 13½" Gal	1430	1830
Unit Complete	4995	5640

3565
785
2780 NET

[illegible] CONNECTIONS			
LETTER	SIZE	TYPE OF LINE	HEIGHT OFF FLOOR
A	½ Galv	Water Return from Still Condenser	39½
B	½ Galv	Water Inlet to Fume & Still Condenser	14¼
C	½ B I	Steam Inlet to Still & Heater Coils	34½
D	½ B I	Steam Return from [illegible]	11½
E	½ B I	Steam Return from Heater Coils	11½
F	½ Galv	Water Return from Fume Condenser	13
G	½ Galv	Electric Feed	48¾

THIS STEEL BASE NOT INCLUDED IN 2 B MACHINE AND FURNISHED AS EXTRA ON 6A MACHINE

HEIGHT FROM FLOOR		
	CONTROL COVER OPEN	TOP OF COND COVER
Without Soap	70½ (Max)	60
With Soap	70½	62 (Max)

FLOOR PLAN
6-A DRY CLEANING UNIT

Fig. 8. Floor plan, dry cleaning unit.

supported by large castings bolted together, and in turn bolted to the head of the hydro-wheel. In the new machine, practically everything on the machine is welded including the motor support bracket, and there is no separate base, no separate storage tank, no separate condenser unit, and we know by experience that there is much less difficulty with parts becoming loose and causing failure of operation.

9, **Less Cost of Installation**—In the case of the old 2B, the hydro-wheel was shipped out separately, the condenser box because of its weight was shipped separately, the storage tank was a separate unit, and all the piping for air, water, steam, etc. was shipped out in separate assemblies. Therefore, it took a service man much longer to install the 2-B machine because of all the assembly work to be done on the job. While there are cases where we cannot ship the 6-A out complete as a unit, this generally can be done, and in any case, since practically all of the various assemblies are contained in the one cabinet, piping, air ducts, electric wiring, etc., are all completed in the factory where it is much more convenient to do this work, and where the time required will be much less. Also, because of vibration in the machine, it is much better to have all the inter-connecting units assembled in one rigid unit rather than to have them mounted separately so that vibration takes place between the separate units. Of course, the still and filter in any of the units are always separate. In the general construction assembly of a 6-A machine, a number of small detail assemblies are mounted on the end plates of the cabinet In most cases where we desire to bolt a flange onto the end plate, we do not find it necessary to machine a surface. Even after galvanizing, we find it only necessary to provide a reasonably thick gasket between the flange of the part to be bolted to the machine and the end plate of the machine In the old 2-B machine it was necessary to do a great deal of machining on the heavy cast iron end plates, and this, naturally, increased the cost.

Summary of Advantages to Purchasers of New 6-A Machine

The selling price of the 2 B machine, less filter, is approximately........$5,000.
The selling price of the 6-A machine, including filter and all accessories, is approximately ....$5,000.
The cost of the filter for the 2B machine is approximately.................. $ 700.
The hourly capacity, or per load capacity, of the new 6-A machine is approximately 50 percent greater than the capacity of the 2-B machine.

The company manufactured other larger machines of the same type as the 2-B, but the 6-A more nearly fills the same capacity requirements.

Saving in Solvent Cost—Big Item

The capacity of 2-B machine, per hour, pounds of garments 35-pounds
The capacity of 6-A machine, per hour, pounds of garments.. .... 52-pounds
Average solvent cost per pound—2 B .. .. $2\frac{1}{4}$¢
Average solvent cost per pound- 6-A . ... $\frac{1}{2}$¢
Assuming 50 lbs. per hour cleaned in 66 A, solvent saving per load .... = 55¢
16 loads per day—saving.......................... = 8.80
300 days per year.......................... = $2,640.

Of course, many machines operate 12- and 14-hours per day, which would increase the above figures.

The 6-A machine has only been on the market a short time, and the shortage of chlorine has stopped the sale of solvent and all synthetic machines for the duration.

Our sales department has figures which indicate that there are approximately 5000 synthetic cleaning machines of all types, both open and closed, in operation. The solvent cost on the open type machines, which comprise more than half of the above figure is from 2½ to 4¢ per pound of garments cleaned. If these machines were replaced with machines as efficient in the use of solvent as the new 6-A machine, the saving to the cleaning industry of solvent alone would be somewhere in the neighborhood of $10,000,000 per year.

The company alone has in operation 400 cleaning machines of all models other than the 6-A machine. When and if these machines are replaced by machines as efficient as the 6-A, the saving to the industry would amount to something like $400,000 per year.

The above figures seem large, but thorough investigation would prove the above figures reasonably correct.

Final Summary of Cost Comparison—The most noticeable cost comparison would be between the 2-B hydro-wheel, and only those assemblies of the 6-A unit, which would correspond to the hydro-wheel.

Because it will be noted that the 2-B hydro-wheel was mostly cast iron, very heavy, and the machining on these castings was quite considerable, the 6-A corresponding assembly included very economically constructed steel cleaner cabinet which cost only........$167.89

Item I. Estimated cost difference between 2-B hydro-wheel and 6-A corresponding assembly $685.00

Note: Above can only be estimated roughly because the hydro-wheel of 2-B machine does not include the recovery unit box, whereas in the 6-A unit it is integral with cabinet, and the same is true of the storage tank, and the air filter housing. Because these units are all included in the one it is difficult to pull out any one of the items from the total cost.

Item 2. Recovery box for complete 2-B unit of cast iron weighs approximately 600-pounds

Cost less coils........$ 78.62

Note that the entire welded 6-A dry cleaner cabinet,

Includes: washer and extractor shell, air filter housing, storage tank 65-gallons, recovery condenser space, air ducts.

Total weight 650-pounds

Total cost $167.89

We therefore estimate recovery condenser space on 6-A constitutes less than 100 pounds of material, and cost would not be more than $15 extra for that portion of cabinet which encloses condenser. Approximate saving........$ 63.62

Item 3. Painting cost on 6-A considerably less. Heavy castings on 2-B require filling and rubbing. 6-A is sprayed and baked only. Estimated saving ....$ 25.00

Item 4. Other savings in constructing the entire unit are involved, but are not necessarily due to welding, but figure in the total difference in cost between the two machines. These savings cover more economical construction of dump valves, air control cylinders, air dampers, air filter units, and general assembly costs between the units. This item, it would appear from the total difference in cost would be approximately........$211.47

Summary of Cost Comparison—Continued

Item 5. The total manufacturing difference, therefore, between the 2-B assemblies, less still and filter, and the 6-A assemblies, less still and filter $985.09

Item 6. Total shipping weight of 2-B machine, approx......... 8800-lbs.
Total shipping weight of 6-A machine
(less steel base) approx............................ 3380-lbs.

Saving .... 5420-lbs.

Note: Average cost of shipping taken as rate from Syracuse to Chicago, LCL, $1.24 per hd. Average saving....................$ 67.20

Item 7. Therefore, the sales spread on 6-A machine exceeds that of the 2-B machine by a grand total of.......................................$1052.29

It is believed this paper has shown that there probably is no other method of building a machine such as the 6-A cleaning unit, except by the use of fabricated and arc welded steel, and at the same time provide the same savings in material and labor, and a product of equal improvement over prior design and construction.

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